National Park Service—Arctic Network
Inventory and Monitoring Program

ARCN

Monitoring Ecological Change in the Arctic Parklands

Vital Signs Monitoring Plan for the Arctic Network Phase 2 Report

Cover photos

Top center: Upper Noatak River near Portage Creek confluence, looking southeast, Mt. Igikpak in background. Photo 2005 by Andrew W. Balser, Institute of Arctic Biology, University of Alaska Fairbanks.

Lower left: Spring beauty (genus *Claytonia*), new species. Siniktanneyak Mtn., Noatak National Preserve. First collected in 1973 by Steven B. Young. Photo 2006 by Andrew W. Balser.

Lower center: American Golden-Plover (*Pluvialis dominica*) in Cape Krusenstern, summer 2005. Photo by Jim Lawler, NPS.

Lower right: Muskox (*Ovibos moschatus*) in Cape Krusenstern, 2004. Photo by Jim Lawler.

MONITORING ECOLOGICAL CHANGE IN THE ARCTIC PARKLANDS

Vital Signs Monitoring Plan for the Arctic Network Phase 2 Report

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"What would you attempt to do if you knew you could not fail?"

—Author Unknown

"Go out on a limb. That is where the fruit is."

—Jimmy Carter

Preface

In 2003, the Arctic Network (ARCN) began the process of planning a long-term ecological monitoring program for the five farthest north national parklands, encompassing over 19 million acres. Phase 2 of this report summarizes three years of progress in designing that program. Completion of a final monitoring plan for the network is anticipated by September 2008 and involves three phases. Phase 1, described in Chapters 1 and 2 of this report, involves defining goals and preliminary objectives; identifying, evaluating, and synthesizing existing data; and developing draft conceptual models. Phase 2 focuses on selecting and prioritizing indicators ("vital signs"). Phase 3 will be the final phase of the monitoring plan and will contain all 10 chapters. The material presented in this report is preliminary and may be revised as additional background information is compiled and the monitoring program develops. Revisions to Chapters 1, 2, and 3 will appear in the Phase 3 report.

In Chapter 1 of this report, we define the purpose and scope of the ARCN monitoring program; explain the process that the network followed in designing the program; describe the ecosystems of ARCN; elucidate potential resource concerns for the parks; define network objectives for freshwater, coastal, and terrestrial ecosystems; provide an exhaustive list of potential monitoring questions for ecosystems of interest; and summarize data mining and joint arctic initiatives. In Chapter 2 we use conceptual models to explain our understanding of the ecosystems of ARCN, current and future anthropogenic impacts to those ecosystems, and the possible ecosystem and landscape-scale consequences of those impacts. In Chapter 3, we describe the process of selecting and prioritizing vital signs for ARCN.

The overall process that ARCN has followed in planning, designing, and implementing its vital signs monitoring program is described in more detail at the National Park Service (NPS) Inventory and Monitoring website (http://science.nature.nps.gov/im/monitor/index.htm). This report, along with all appendices and other information from both the Phase 1 and Phase 2 reports, is available on the Arctic Network website (http://www1.nature.nps.gov/im/units/arcn/index.cfm).

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Acknowledgements

Thank you to President Jimmy Carter for signing the most significant land conservation measure in the history of our nation, the Alaska National Interest Lands Conservation Act (ANILCA), into law. Without your dedication to these public trust resources the 19.3 million acres of national parklands that make up the Arctic Network (ARCN) would not exist as such.

The authors thank Jefferson Jacobs, Andrew Balser, Torre Jorgensen, Jennifer Mitchell, Cathy Cahill, Peter Neitlich, and Jennifer Allen for helping with various sections of this report. Torre Jorgenson's and Jennifer Mitchell's help with conceptual models was invaluable.

We thank our past and present technical committee members Jim Lawler, Peter Neitlich, Amy Larsen, Jennifer Allen, Brad Shults, Thomas Liebscher, Thomas Heinlein, Ken Adkisson, Lois Dalle-Molle, Karen Oakley, and Sara Wesser for participation in meetings and scoping workshops. Without their thoughtful input and dedication, this document would not have been possible.

Thank you Gates of the Arctic (GAAR), Western Arctic Parklands (WEAR), and Alaska Region Office staff for your support of ARCN. In addition to the technical committee, the resource staff in WEAR and GAAR have helped guide our program and given us useful input at various stages, especially Fred Andersen, John Burch, Melanie Cook, Donna DiFolco, Eileen Devinney, Bob Gal, Nikki Guldager, Linda Hasselbach, Dave Krupa, Charlie Lean, and Jeff Rasic. Thank you to Amy Larsen, Jim Lawler, Jennifer Allen, and Thomas Liebscher for thoughtful review of earlier versions of this report.

Many thanks to all of our workshop participants from the local communities, other agencies, and academia. Your input has been essential in helping design a scientifically sound, ecologically based, and management-relevant monitoring program for ARCN.

We thank the current and past members of the ARCN Board of Directors: Sara Wesser, Dave Spirtes, Thomas Heinlein, George Helfrich, Julie Hopkins, Brad Bennett, Dave Mills, and Bob Winfree for their thoughtful insights and support of ARCN.

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Last but not least, we thank the other three past and present Alaska network coordinators, Maggie MacCluskie, Alan Bennett, and Chiska Derr for their support, camaraderie, and setting the example for ARCN to follow in Alaska.

Executive Summary

- The National Park Service's Inventory and Monitoring (I&M) Program is vital to fulfilling the National Park Service's (NPS) mission of protecting and preserving the natural resources of the national park system unimpaired for the use and enjoyment of current and future generations. Established in 1992, the purpose of the I&M program is to "develop scientifically sound information on the current status and long term trends in the composition, structure, and function of park ecosystems, and to determine how well current management practices are sustaining those ecosystems." The principal functions of the program are to: (1) gather baseline information about park ecosystems, (2) develop techniques and strategies for monitoring ecological communities, and (3) provide crucial scientific information to park managers so that better-informed scientifically sound management decisions can be made.
- National parks with significant natural resources have been grouped into 32 monitoring networks linked by geography and shared natural resource characteristics. The network approach facilitates collaboration, information sharing, and economies of scale in natural resource monitoring. Parks within each of the 32 networks work together and share funding and professional staff to plan, design, and implement an integrated long-term monitoring program.
- The Arctic Network (ARCN) includes five NPS system units (Figure 1): (1) Bering Land Bridge National Preserve (BELA), (2) Cape Krusenstern National Monument (CAKR), (3) Gates of the Arctic National Park and Preserve (GAAR), (4) Kobuk Valley National Park (KOVA), and (5) Noatak National Preserve (NOAT). Collectively these units represent approximately 19.3 million acres, or roughly 25% of the land area of NPS-managed units in the United States.
- Administratively, the parklands in ARCN are managed as three units: (1) Western Arctic Parklands (WEAR), which consists of one monument (CAKR), one park (KOVA) and one preserve (NOAT), is managed by a superintendent in Kotzebue; (2) BELA, which is managed by a superintendent in Nome; and (3) GAAR, which is managed by a superintendent in Fairbanks, with field offices in Bettles and Coldfoot. The park headquarters for all five parks are outside the park boundaries and the parks themselves are accessible only by airplane, boat, or on foot. This creates a unique and interesting challenge for creating a long-term monitoring program.
- The large land area of ARCN parks and the differences in resource management priorities among parks were perceived as the greatest challenges facing the network. However, during our park scoping workshops and superintendent interviews, we found that the ARCN parks share the same resource management concerns and monitoring needs.
- ARCN's mission is to create a long-term monitoring program that deepens the understanding of the boreal and arctic ecosystems represented in the parks, integrates knowledge of the park ecosystems with the circumpolar North and the world in general, and informs wise management decisions and the preservation of park values.
- ARCN held a series of scoping workshops to provide a forum for NPS resource managers and scientists to discuss ideas for building a statistically sound, ecologically based, management-relevant, and affordable monitoring program for ARCN. The scoping workshops were designed to gain

expert advice from a broad array of scientists who have performed or are familiar with ecological research in northern Alaska. The input from these meetings was used to (1) develop a set of conceptual models of the natural and anthropogenic features and processes within the parks, (2) develop a list of monitoring objectives for ecosystems of significance, and (3) identify an exhaustive list of candidate attributes or components ("vital signs") to monitor that would provide reliable signals about condition of the ecosystem.

- The ARCN monitoring program will be designed around the five service-wide goals. In addition, the ARCN staff and outside experts drafted the following criteria for a successful monitoring program for the difficult-to-access remote parklands of the Arctic. We thought the program would be successful if it was foundational; relevant to arctic ecosystems and arctic ecosystem science and monitoring; of interest to local, circumpolar, and global communities; took an integrative and efficient approach; was collaborative, cost-effective, and comprehensive; was achievable (realistic regarding access, logistics, etc.); valuable to park managers and scientists; and complemented the "infrastructure capital."
- ARCN data mining efforts have focused on two fronts: assembling a natural resource bibliography and identifying sources of high-quality inventory and monitoring data and collaborations. In 2004 we made great progress on populating the national Inventory and Monitoring bibliography, NatureBib, with publications about arctic park ecosystems. ARCN also began data mining efforts with the goal of identifying present and historical resource inventories and monitoring efforts. While this effort is still beginning and will likely be an ongoing process through the life of the program, we have made a preliminary list of agencies, programs, existing ecological inventories, and long-term studies that may be of value to ARCN.
- Throughout the last decade, there have been a number of major international research and monitoring initiatives of significance to ARCN. In order for ARCN to develop a successful monitoring program, participation in national and international initiatives will be of the utmost importance (e.g., International Polar Year, High Latitude Ecological Observatory Network [HLEO-NEON].
- ARCN held three scoping workshops that were designed, in part, to help network staff develop a set of conceptual models of the natural and anthropogenic features and processes of the enormous areas included in the parks. Each of the three workshops tackled one of three areas of interest to ARCN: freshwater, coastal-influenced, and terrestrial ecosystems. Conceptual models developed during the scoping workshops were reproduced in a computer graphics program and placed in workshop output summary documents. Information from the workshops was then interpreted and summarized into 3-D landscape-scale conceptual ecosystem models. Our hope is that the models presented in Chapter 2 will (1) help to describe the complex ecosystems of ARCN, (2) elucidate current and potential anthropogenic stressors to ARCN ecosystems, (3) suggest potential mechanisms by which these drivers and anthropogenic stressors could impact ARCN ecosystems, and (4) help lay the foundation for monitoring critical aspects of the environment of the parks.
- There are 27 vital signs identified in Chapter 3 for the Arctic Network Monitoring Plan. These vital signs are presented in both the National Park Service's Vital Signs Framework and in ARCN's overarching conceptual model. This list of vital signs represents the culmination of a three-year process in which ARCN tried to take an ecosystems-based approach to monitoring. Major components of air, land, and water in ARCN are included in this list, with physical, chemical, and biological attributes tied to each of the major ecosystem types (freshwater, terrestrial, and coastal). Several of our vital signs cross traditional ecosystem boundaries and so take a more landscape/watershed approach to monitoring. The ARCN monitoring program will spend the majority of its time focusing on 14 of these vital signs because they are: (1)sensitive indicators of change, (2) relevant at various temporal and spatial scales, (3) important for sound management, (4) strongly linked with other vital signs, and (5) not already being monitored.

Chapter 1

Introduction and Background

"Sentiment without action is the ruin of the soul.
One brave deed is worth a thousand books."

—Edward Abbey

1.1 Importance of Monitoring

Effective management of America's parklands requires not only a broad understanding of their enabling legislation and purpose, but also demands a clear, scientifically derived concept of their past and potential future condition. In recognition of the fact that such critical information is frequently unavailable for park managers who must solve real-world problems using anecdotal, qualitative, or incomplete data, the National Park Service has committed to providing high-quality information about the condition of park resources through its Inventory and Monitoring (I&M) Program.

Established in 1992, the purpose of the I&M Program is to "develop scientifically sound information on the current status and long-term trends in the composition, structure, and function of park ecosystems, and to determine how well current management practices are sustaining those ecosystems" (NPS 2006). In order to accomplish this mission, the I&M program set out to:

1. provide a consistent database of information about our natural resources, including species diversity, distribution, and abundance (12 Basic Inventories);

and

2. determine the current condition of our resources and how they are changing over time.

Such information will help judge the efficacy of management decisions, elucidating potential threats to valued ecological components, and determining which trends in a fundamentally dynamic system are natural and which may be human-induced and potentially deleterious. Similarly, some systems are naturally variable, and a monitoring program can help determine what variation can be expected over an arbitrary time period. Such data can be advantageous in defining what limit of variability may be characterized as impairment. A good monitoring program also recognizes that anthropogenic influences do not respect political boundaries. Baseline inventory and monitoring efforts must therefore be collaborative in nature to provide a better-informed and broader landscape-level spatial perspective to problems that may otherwise be viewed with a more constrained and localized eye.

By approaching ecosystem monitoring with such an innovative, holistic, and, by necessity, interdisciplinary approach, the I&M Program has become a de facto leader, breaking new ground in the realm of ecosystem monitoring. A side consequence of this notoriety is that we will be watched and emulated, resulting in added pressure to get it right the first time through. It is our hope that the care and effort put into this monitoring plan will result in a dramatic improvement in park administrators' ability to make rapid, informed, and beneficial policies to protect park resources, inform visitors about the workings of their park ecosystems, and preserve them for future generations.

1.2 NPS Policies, Mandates, and Legislation That Link Ecosystem Monitoring with Park Management

1.2.1 Policies, Mandates, and Legislation

The I&M Program is vital to fulfilling the NPS's mission of protecting and preserving the natural resources of the national park system unimpaired for the use and enjoyment of current and future generations. The National Park Service Organic Act of 1916 clearly states that NPS lands will be managed

> *to promote and regulate the use of the Federal areas known as national parks, monuments, and reservations hereinafter specified by such means and measures as to conform to the fundamental purposes of the said parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.*

More recently, the National Parks Omnibus Management Act of 1998 established the framework for fully integrating natural resource monitoring and other science activities into the management processes of the national park system. The act charges the secretary of the interior to "continually improve the ability of the National Park Service to provide state-of-the-art management, protection, and interpretation of, and research on, the resources of the National Park System," (U.S. Congress 1998, Title I, Section 101) and to "assure the full and proper utilization of the results of scientific studies for park management decisions" (Title II, Section 206).

The lack of scientific information about resources under NPS stewardship has been widely acknowledged as inconsistent with NPS goals and standards. In 1992 the National Academy of Science recommended that "if this agency is to meet the scientific and resource management challenges of the twenty-first century, a fundamental metamorphosis must occur" (National Research Council et al. 1992 p. 13).

Congress reinforced this message in the text of the FY2000 Appropriations Bill:

> *The Committee applauds the Service for recognizing that the preservation of the diverse natural elements and the great scenic beauty of America's national parks and other units should be as high a priority in the Service as providing visitor services. A major part of protecting those resources is knowing what they are, where they are, how they interact with their environment and what condition they are in. This involves a serious commitment from the leadership of the National Park Service to insist that the superintendents carry out a systematic, consistent, professional inventory and monitoring program, along with other scientific activities, that is regularly updated to ensure that the Service makes sound resource decisions based on sound scientific data.*

The nationwide Natural Resource Challenge program was put in place to revitalize and expand the natural resource program of the National Park Service. This effort increased funding to the I&M Program to facilitate improved baseline and long-term trend data for NPS natural resources. To efficiently and fairly use the funding available for inventories and monitoring, the 270 National Park Service units with significant natural resources managed by the service were organized into 32 biome-based networks (Figure 1.1). Four networks were established in Alaska, clustering park units that share similar ecosystems and mandates (Figure 1.2). These networks have been designed to share expertise and infrastructure for both biological inventories and development of long-term ecological monitoring programs.

Figure 1.1. National Inventory and Monitoring Networks

1.2.2 Role of Monitoring in Park Management

The overall goal of natural resource monitoring in the national parks is to develop scientifically sound information on the current status and long-term trends in the composition, structure, and function of park ecosystems and to determine how well current management practices are sustaining those ecosystems.

Every government entity, including the NPS and each of its national parks, is required by the Government Performance and Results Act of 1993 (GPRA) to produce a five-year Strategic Plan with measurable goals. In 2004 all agencies and services within the Department of the Interior, including the NPS, merged their goals into a unified set of department goals. The ARCN I&M Program addresses questions that relate to 10 NPS GPRA goals (Table 1.1).

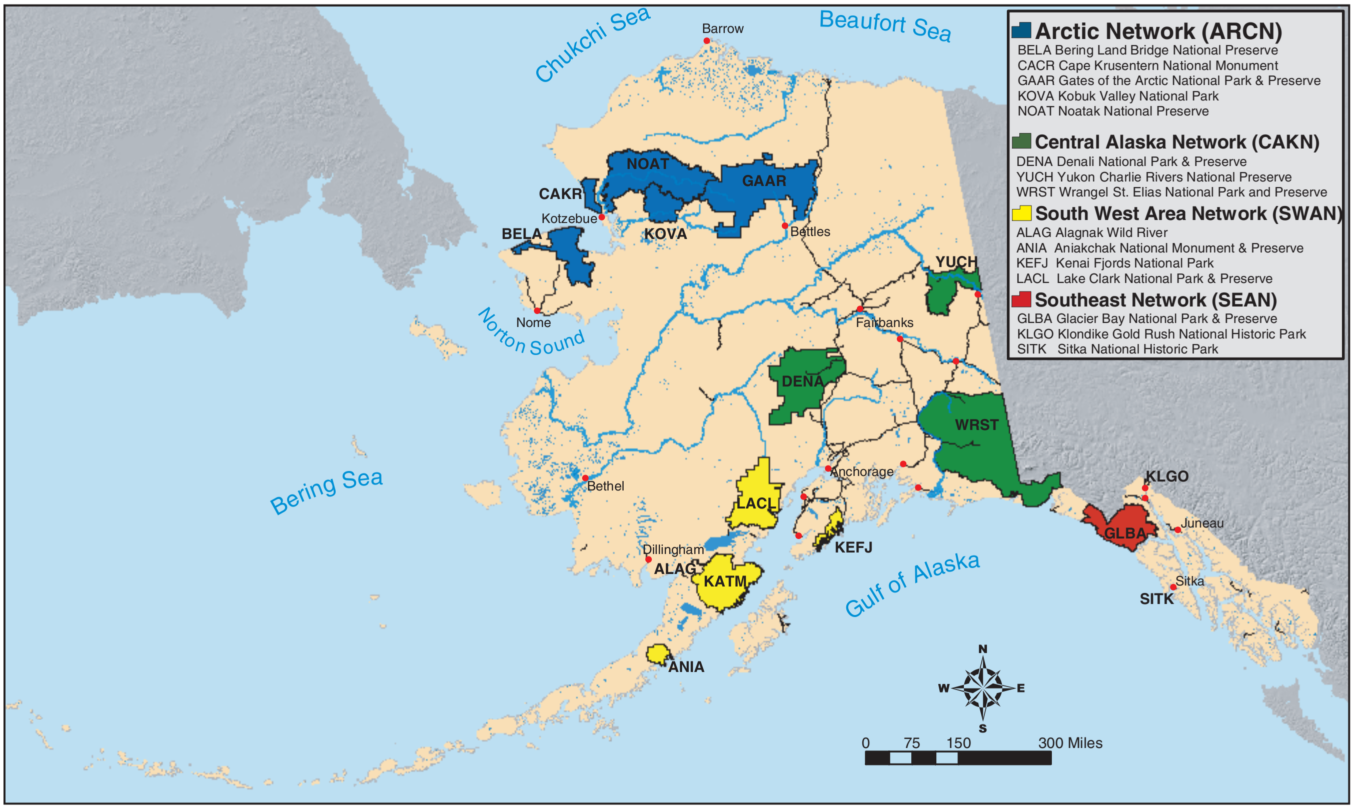


Figure 1.2. Alaska Region Inventory and Monitoring Networks

Table 1.1. Government Performance and Results Act goals

NPS-GPRA GOAL	Brief Description of NPS Goal	APPLICABILITY TO PARK				
		BELA	CAKR	GAAR	KOVA	NOAT
Long-Term Goal 1a1C	Land-Health Goal: Wetlands	X	X	X	X	X
Long-Term Goal 1a1D	Land-Health Goal: Riparian and Streams	X	X	X	X	X
Long-Term Goal 1a1E	Land-Health Goal: Uplands	X	X	X	X	X
Long-Term Goal 1a1F	Land-Health Goal: Marine and Coastal	X	X	—	—	—
Long-Term Goal 1a2B	Species of Management Concern	X	X	X	X	X
Long-Term Goal Ia3	Air quality in 70% of the reporting park areas has remained stable or improved	X	X	X	X	X
Long-Term Goal Ia4 (a&b)	85% of park units will have unimpaired water quality	X	X	X	X	X
Long-Term Goal Ib1	Acquire or develop 87% of the outstanding data sets identified in 1999 of basic natural resource inventories for all parks	X	X	X	X	X
Long-Term Goal Ib3	80% of 265 parks with natural resources have vital signs for natural resource monitoring	X	X	X	X	X
Long-Term Goal Ib4	Geologic processes are inventoried and human influences that affect them identified	X	X	X	X	X

1.3 The Arctic Network

The Arctic Network (ARCN) is one of 32 inventory and monitoring networks nationally and one of four in Alaska. The network includes five NPS units (Figure 1.3):

- Bering Land Bridge National Preserve (BELA),
- Cape Krusenstern National Monument (CAKR),
- Gates of the Arctic National Park and Preserve (GAAR),
- Kobuk Valley National Park (KOVA), and
- Noatak National Preserve (NOAT).

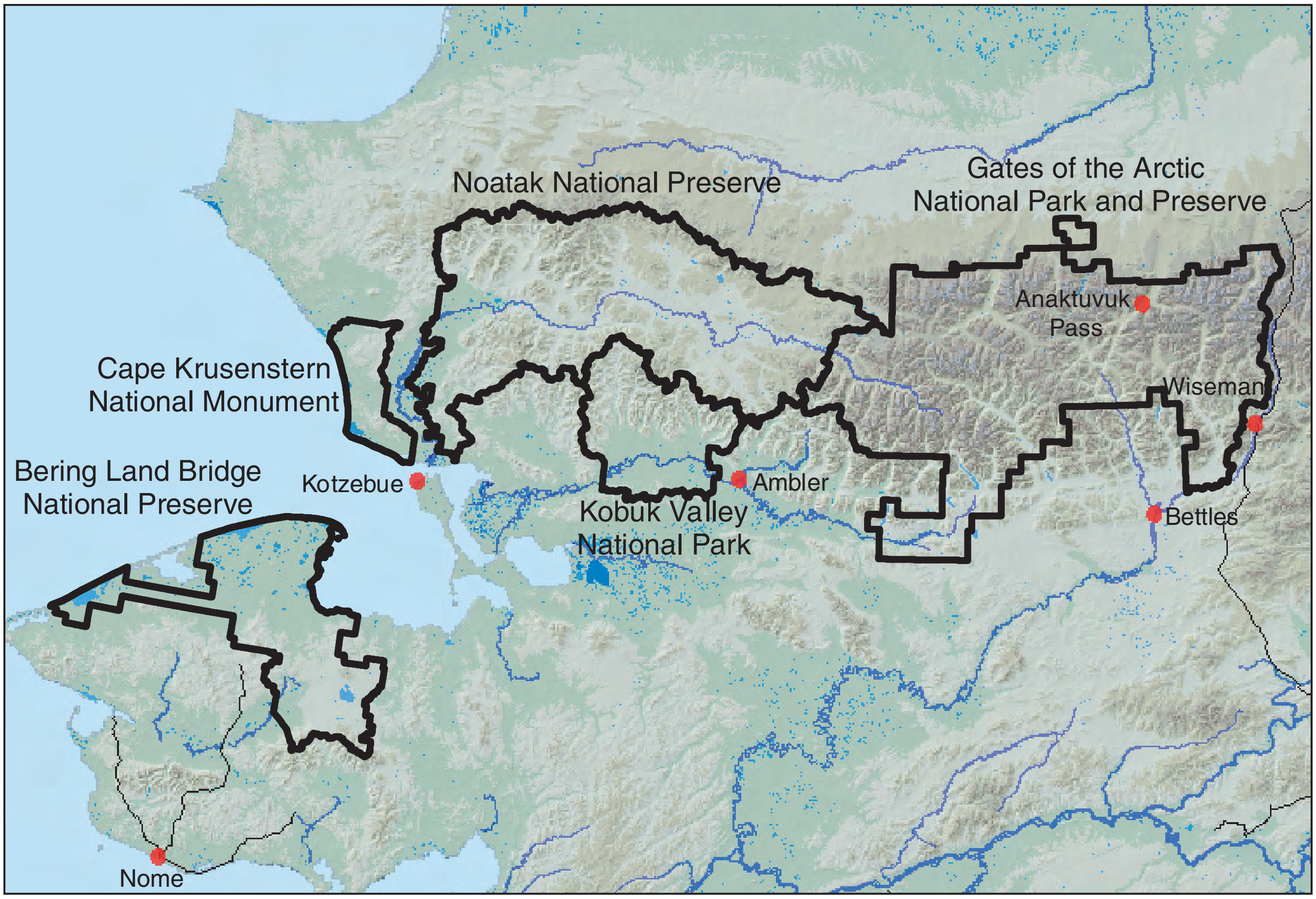


Figure 1.3. The Arctic Network

Collectively, these units represent approximately 19.3 million acres, or roughly 25% of the land area of NPS-managed units in the United States. GAAR, KOVA, and NOAT are contiguous and encompass a large expanse of mostly mountainous arctic ecosystems at the northern limit of treeline. Immediately to the west of these units lie CAKR and BELA, which border Kotzebue Sound, the Bering Strait, and the Chukchi Sea. BELA and CAKR are similar with respect to their coastal resources and strong biogeographic affinities to the Beringian subcontinent, the former land bridge between North America and Asia. The ARCN park units are not connected to the road system. Much of the ARCN is designated or proposed wilderness.

All of the NPS units within the ARCN parks are relatively recent additions to the national park system. Portions of BELA, CAKR, and GAAR were initially created by presidential proclamation in 1978. All five units were redesignated or created with their present boundaries by the Alaska National Interest Lands Conservation Act (ANILCA) in 1980. The recent origin of these remote and difficult-to-access units, coupled with limited natural resource staffing levels, has left the natural resources in these units relatively under-studied.

Administratively, the parklands in ARCN are managed as three units: (1) Western Arctic Parklands (WEAR), which consists of one monument (CAKR), one park (KOVA), and one preserve (NOAT), managed by a superintendent in Kotzebue; (2) BELA, which is managed by a superintendent in Nome; and (3) GAAR, which is managed by a superintendent in Fairbanks, with field offices in Bettles and Coldfoot. The park headquarters for all five parks are outside the park boundaries and the parks themselves are accessible only by airplane, boat, or on foot. This creates a unique and interesting challenge for creating a long-term monitoring program.

1.4 ARCN's Approach to Designing a Monitoring Program

1.4.1 Our Mission Statement

The National Park Service's Arctic Network (ARCN) will create a long-term monitoring program that deepens the understanding of the boreal and arctic ecosystems represented in the parks, integrates knowledge of the park ecosystems with the circumpolar North and the world in general, and informs wise management decisions and the preservation of park values.

1.4.2 Timeline for ARCN

The Arctic Network received initial funding from the servicewide I&M Program to conduct biological inventories in FY2001. In FY2003 ARCN received initial funding for vital signs monitoring. A network coordinator was hired in June 2003 to begin designing the monitoring program. In FY2003 the Board of Directors and Technical Committees were formed and each adopted charters. Also in FY2003 ARCN held park scoping workshops and informally interviewed staff in each of the five parks. In FY2004 ARCN received funds to continue inventories of vascular plants and vertebrates, and startup funds for initiating the water quality and vital signs monitoring programs. In FY2004 the network data manager was hired and two of the three scoping workshops were held. In FY2005 the network received full funding for vital signs and water quality monitoring. In 2005 and 2006 the remaining two scoping workshops were held. Also in 2006 vital signs were selected. The first draft of the monitoring plan (Phase 3) is due December 2007. The final monitoring plan will be complete in September 2008 (Figure 1.4).

1.4.3 Network Personnel Structure and Function

In order for this program to be highly accessible and useful to park managers, each network was advised to establish a board of directors and technical advisory committee to help plan and implement the monitoring program (Figure 1.5). The ARCN Board of Directors consists of three superintendents representing the park units, the Alaska regional I&M coordinator, the ARCN I&M coordinator, and the Alaska regional science advisor. The nine-member technical advisory committee (TAC) consists of the chiefs of resource management from each park unit, two natural resource scientists from each

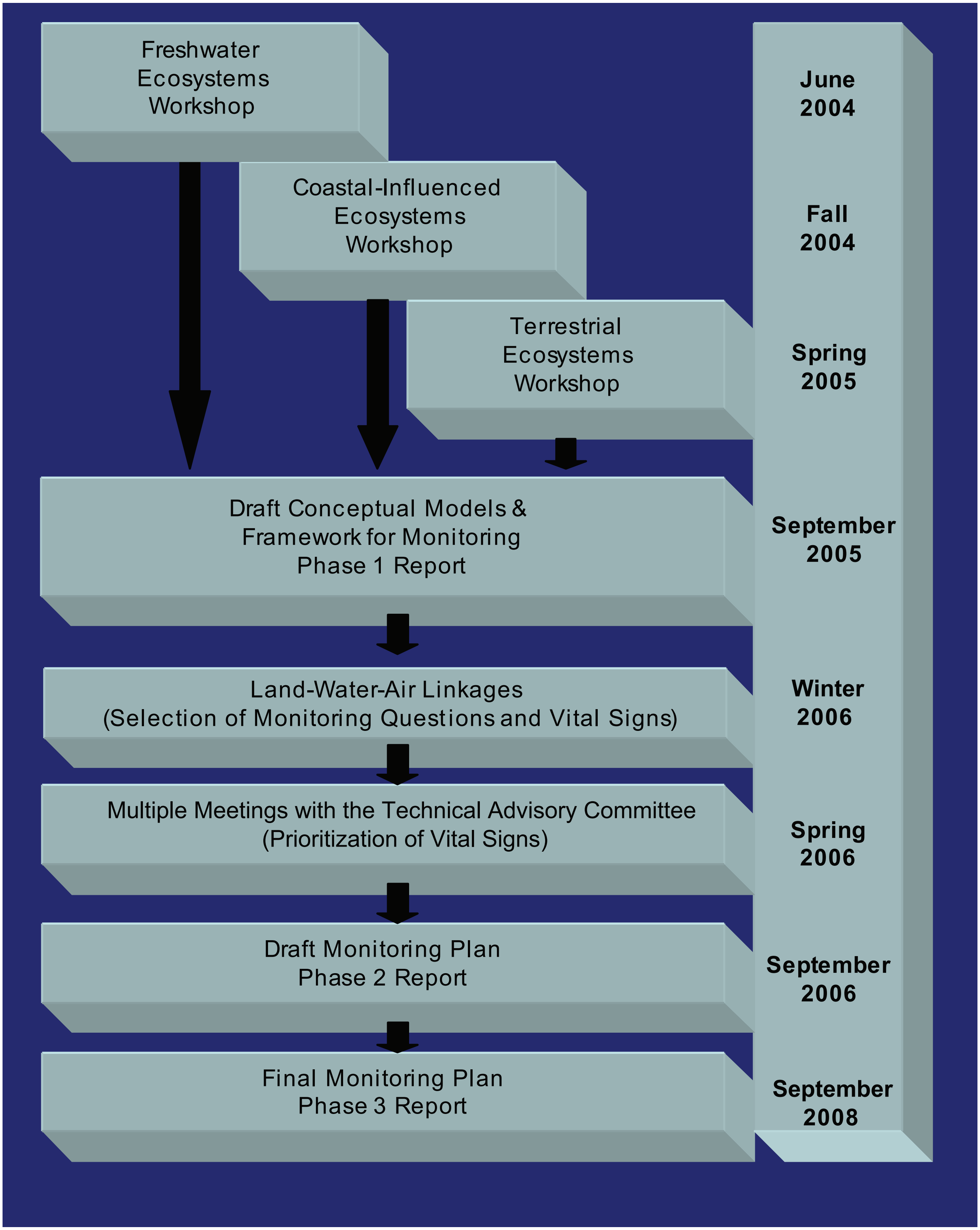


Figure 1.4. Timeline for ARCN monitoring plan development

park unit, a regional fire ecologist, the ARCN I&M coordinator (chair), and the Alaska Cooperative Ecosystem Studies Unit (CESU) coordinator. The TAC meets several times a year to determine monitoring objectives, vital signs, overall goals of the program, and to discuss staffing and budget projections. The coordinator also meets with a variety of working groups to discuss specific aspects of the program on a regular basis. These smaller working groups are composed of members of the technical committee and park staff. These smaller working groups advise the TAC on specific aspects of network functions. Consultation with scientific experts and peer review has been crucial in the development of this program.

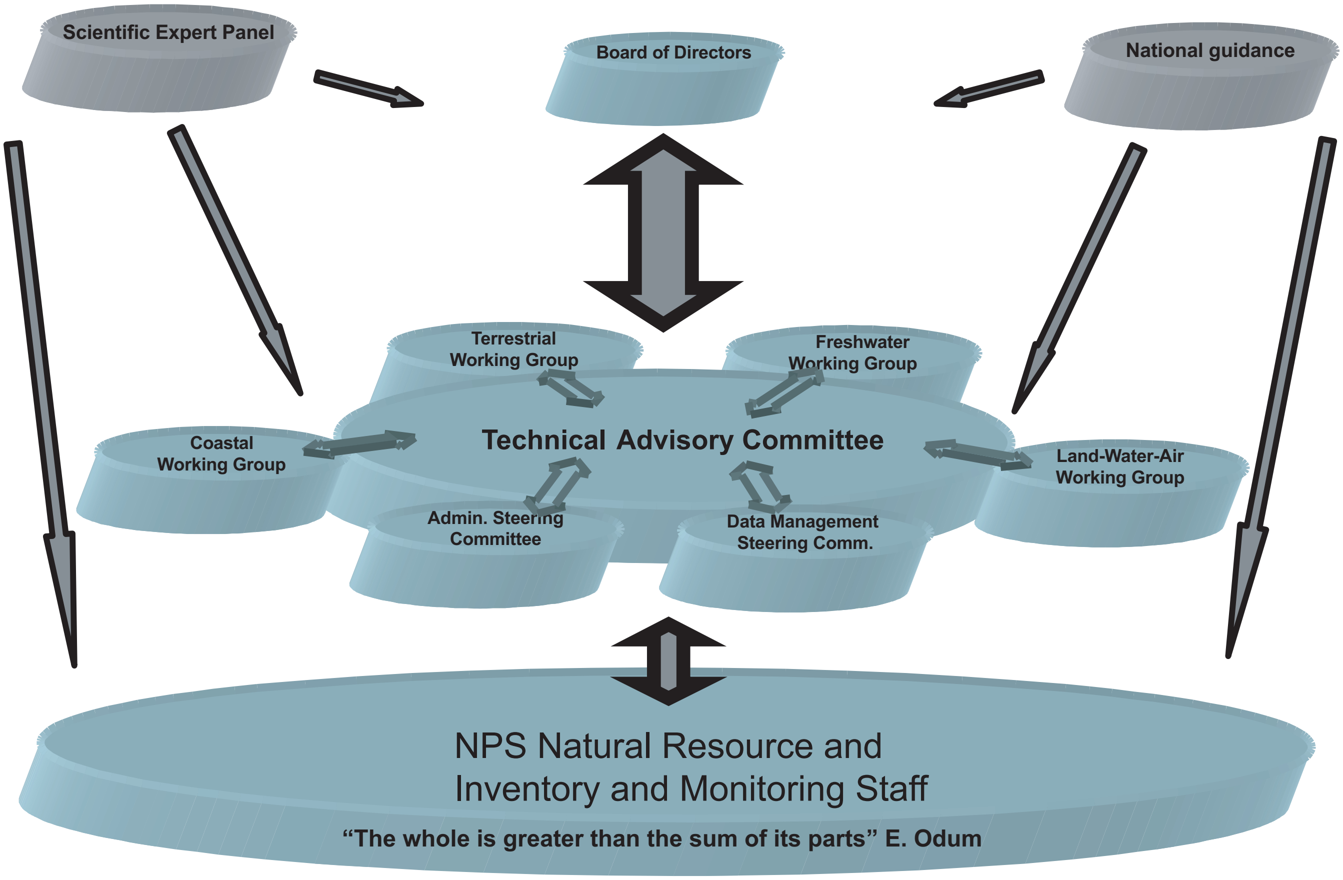


Figure 1.5. Arctic Network personnel structure

1.4.4 Planning Process for Developing the ARCN Monitoring Plan

In order to achieve the above goals, ARCN is following the basic approach to designing a monitoring program laid out in the national framework. The process involves five key steps:

1. Define the purpose and scope of the monitoring program.
2. Compile and summarize existing data and understanding of park ecosystems.
3. Develop conceptual models of relevant ecosystem components.
4. Select indicators and specific monitoring objectives for each.
5. Determine the appropriate sampling design and sampling protocols.

These five steps are incorporated into a three-phase planning process that has been established for the NPS monitoring program (Figure 1.6). Phase 1 involves defining goals and objectives; beginning the process of identifying, evaluating, and synthesizing existing data; developing draft conceptual models; and determining preliminary monitoring questions. Phase 2 involves refining the conceptual ecosystem models and selecting "vital signs" that will be used as indicators to detect change. Phase 3 of the planning process involves determining the overall sample design for monitoring, developing protocols for monitoring, and producing a data management plan for the network.

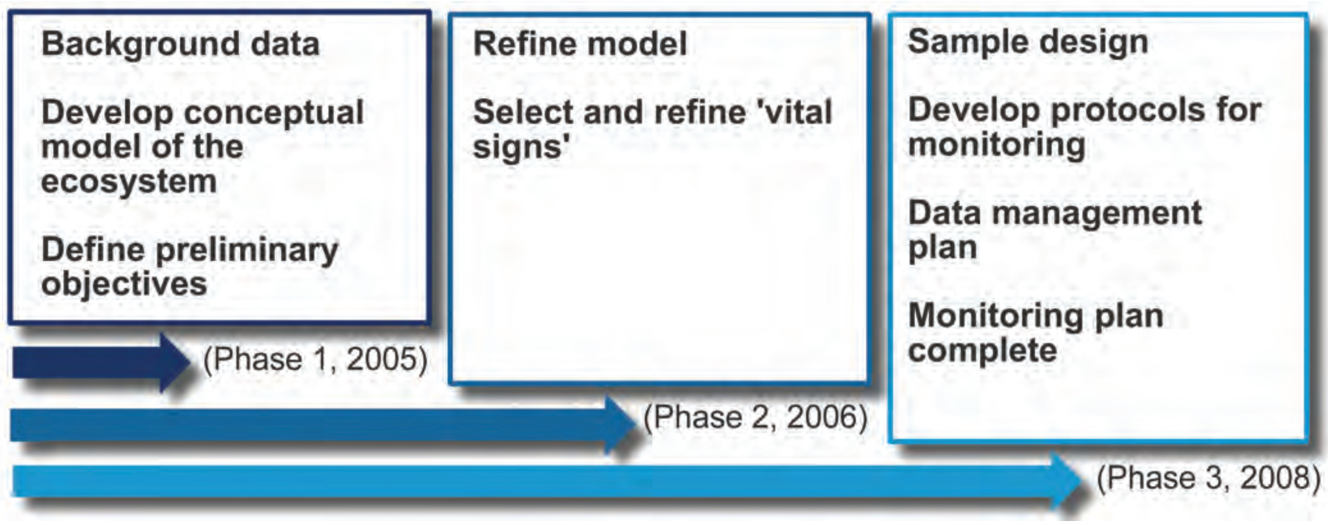


Figure 1.6. ARCN three-phased approach to monitoring program development

1.4.5 Scope of the ARCN Monitoring Plan

ARCN held a series of scoping workshops to provide a forum for NPS resource managers and scientists to discuss ideas for building a statistically sound, ecologically based, management-relevant, and affordable monitoring program for ARCN. The scoping workshops for ARCN were designed to gain expert advice from, and initiate longer term consultation with, a broad array of scientists who have performed or are familiar with ecological research in northern Alaska. The input from these meetings was used to: (1) develop a set of conceptual models of the natural and anthropogenic features and processes within the parks (Chapter 2); (2) develop a list of monitoring objectives (see below); and (3) identify candidate attributes or components to monitor that would provide reliable signals about condition of the ecosystem.

Our strategy for this initial set of workshops was to create large scale conceptual models and an exhaustive list of monitoring objectives from participant input. Over time these could be reduced to a more focused set of conceptual models, monitoring objectives, list of priority "vital signs" and eventually a detailed plan for monitoring critical aspects of the environment of the parks. It is expected that the data gathered in this program will provide scientifically credible information to park management to conserve their environmental integrity indefinitely. A valuable additional effect of this work should be to provide useful data and insights into the broader concerns of understanding and protection of the environment of the circumpolar North (Figure 1.7).

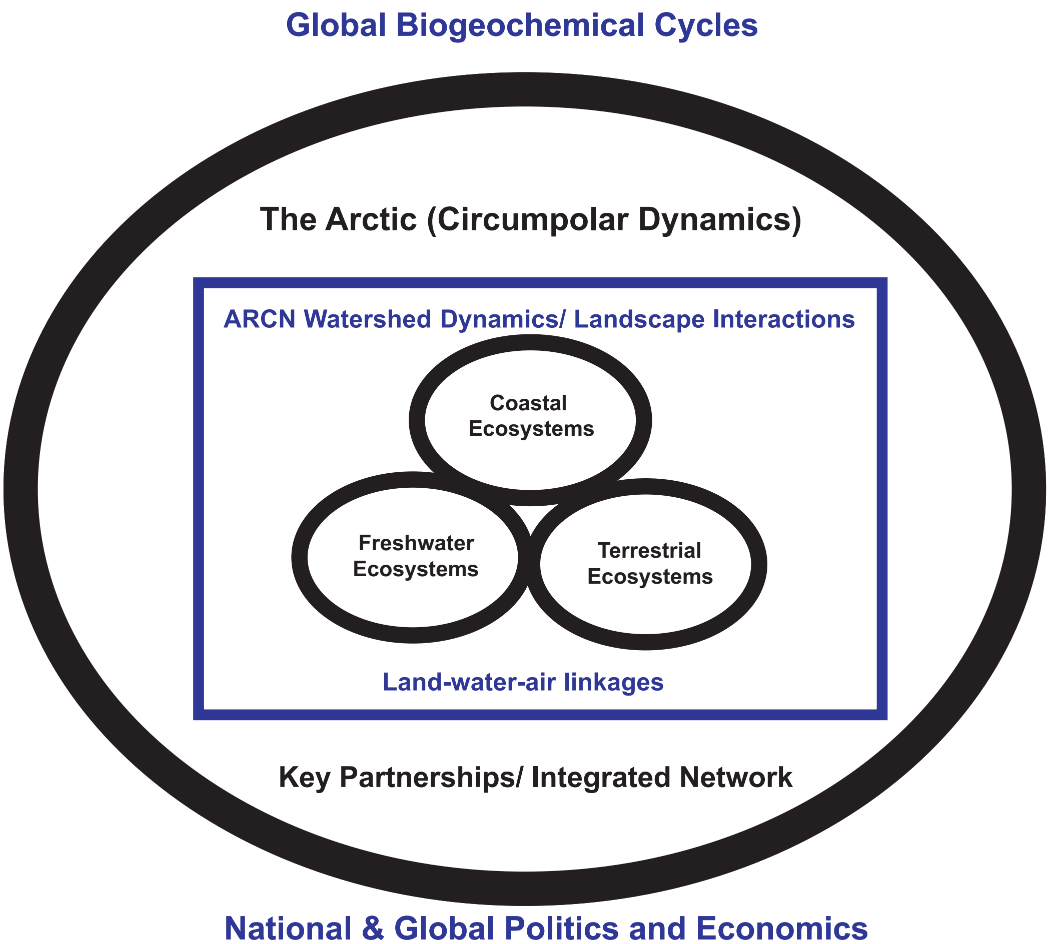


Figure 1.7. Conceptual model showing how ARCN ecosystems fit within a national and global context

Long-term monitoring is increasingly recognized as an essential tool for understanding and managing environments at many levels of geographical scale. Thus, long-term monitoring is much more than the random gathering of data. Ideally, it is an evolving process that is guided by several concepts:

Efficiency: Monitoring must strive to get the maximum amount of useful information from a sampling system that is limited by factors such as cost, logistical concerns, and availability of trained personnel.

Relation to the broader world: Monitoring benefits from, and provides for, the exchange of useful information with comparable environments, even if they are being managed for different purposes, or have only minimal management programs or plans.

Flexibility: Monitoring plans must be able to incorporate new information and concepts and evolve with increased understanding of the ecosystems under study.

Scale: Monitoring deals with processes that take place over widely varying amounts of time and space. It must be designed to provide information on both local, often rapidly proceeding, processes and those that occur over longer times and/or broader geographical areas.

Dynamism: Monitoring plans must recognize that ecosystems are never static, and that even without anthropogenic impacts, complex changes will always be occurring.

1.4.6 Criteria for a Successful Monitoring Plan in the Arctic Parks

The ARCN Technical Committee and invited scientific experts attending the Freshwater Scoping Workshop realized the enormity of the task of creating a statistically sound, ecologically based monitoring program that would be representative of 19.3 million acres of arctic and subarctic ecosystems. They came up with the following draft criteria for monitoring in ARCN. The list was further reviewed by outside experts attending the Coastal and Terrestrial Ecosystem Workshops. This list was the starting point from which the TAC developed the vital signs criteria used to determine if proposed vital signs meet the goals of the monitoring program (see Chapter 3 for more detail).

List of criteria for a successful approach to monitoring:

- Foundational
- Relevant to arctic ecosystems and arctic ecosystem monitoring
- Of interest to local, circumpolar, and global communities
- Takes an integrative and efficient approach
- Collaborative
- Cost-effective
- Comprehensive
- Achievable (realistic regarding access, logistics, etc.)
- Valuable to park managers and scientists
- Complement the "infrastructure capital"

1.5 Park Scoping Workshops

In FY2003 and FY2004 the network staff met with park and regional staff in formal and informal settings. In order to involve park staff in the initial stages of developing a monitoring program, and to determine the real and perceived challenges in "thinking like a network," ARCN staff held park scoping workshops.

The workshops began with an overview of the Natural Resource Challenge, the national goals of the I&M Program, and our vision for ARCN. A round table discussion of past, current, and future work of relevance to the monitoring program ensued. We then asked: What are the major ecological drivers in ARCN parks? What are the current (and future) stressors to ARCN parks? What is the most appropriate time scale for monitoring in the arctic parks? What are the most important stressors to ARCN parklands right now? What are the perceived future impacts to ARCN parklands in the next 10 years, 30 years, 50 years? Staff in all three management units were concerned with the same anthropogenic impacts to park ecosystems (see Chapter 2). A series of nested conceptual models were developed based on input from the park workshops. The scientific experts on the technical committee helped refine these models. The models were then inserted into the formal scoping workshop notebooks to provide necessary background information to scientific experts outside of NPS. The models were reviewed and modified by these experts after the formal scoping workshops (see below).

Before the park miniworkshops, differences in resource management priorities among parks were perceived as the greatest challenges facing the network. However, during our park scoping workshops and superintendent interviews, we found that the ARCN parks share the same resource management concerns and monitoring needs.

1.6 Ecosystem Monitoring Scoping Workshops: Freshwater, Coastal, and Terrestrial Scoping Workshops

The Arctic Network held a series of scoping workshops to provide a forum for NPS resource managers and scientists to discuss ideas for building a statistically sound, ecologically based, management-relevant, and affordable monitoring program for ARCN. In three of these workshops, we delineated the landscape into freshwater, coastal-influenced, and terrestrial ecosystems. Although we realize this division is somewhat arbitrary, it enabled us to strategically separate ARCN ecosystems into more manageable subunits for the purposes of discussion. A fourth workshop, land-air-water linkages (LAW), was held in January 2006 where participants were asked to take a larger, landscape-scale approach to thinking about monitoring in ARCN.

The workshops were built around a series of small working group sessions in which invited experts focused on particular ecological subjects. The overall objectives of the meetings were to: (1) create and refine conceptual models, (2) develop a comprehensive list of potential monitoring questions, (3) identify potential ecosystem attributes of interest ("vital signs"), and (4) determine possible measures for those vital signs. (See Phase 1 Workshop Appendices 1–6 at <http://www1.nature.nps.gov/im/units/arcn/documents/index.cfm> for more detail.)

To facilitate better discussion during the workshops, the ARCN staff assembled extensive background materials for each of the parks. This background material was put into a scoping notebook and given to each of the participants well in advance of the meeting (see Phase 1 Appendices 1 and 3, available at <http://www1.nature.nps.gov/im/units/arcn/documents/index.cfm>). Included in the notebook were worksheets that helped the participants prepare for the workshop.

Each of the first three workshops followed a formula in which the first afternoon and following morning were spent in a large group, gaining background information on the specific ecosystem components (e.g., birds, soils, vegetation), the drivers and/or anthropogenic stressors that impact them (e.g., climate, fire, visitor impacts, adjacent North Slope development), and possible ecosystem responses. During the second day, the group divided into smaller working groups of six to twelve, which were given the task of commenting on, revising, or replacing existing models as needed for thoroughness, accuracy, descriptive quality, etc. These new and revised models were presented to and further refined by the larger group. The second task on day two was to break up into small groups and, with the ecosystem models in mind, work toward developing monitoring questions and proposing preliminary vital signs. Each group then shared its results with the larger group. After reviewing our progress with the whole group, we reconvened in a second working group session. Having heard everyone else's proposed monitoring questions, we identified each group's highest priority questions.

By the end of the third day, we had recorded potential monitoring questions in a database. In addition, we had expert opinions on which questions were the most compelling for ARCN and how we might go about answering them. We also compiled a list of potential partners that may be willing to collaborate and share costs.

Products from each of the workshops were compiled into a workshop summary report (see Phase 1 Appendices 2, 4, and 6, available at <http://www1.nature.nps.gov/im/units/arcn/documents/index.cfm>). The summary report included three-dimensional conceptual models that were created based on input gleaned from the scoping workshops, potential monitoring questions, possible ecosystem components or attributes of interest, and discussion notes. These summary reports were placed on the ARCN web site for further comment and review by all workshop attendees and technical committee members.

1.7 Land-Air-Water Linkages: Integrating Vital Signs Monitoring With Water and Air Quality Monitoring

Our fourth and final workshop, Land-Water-Air Linkages (LAW) was held in January 2006. The ARCN Board of Directors, ARCN Technical Advisory Committee, ARCN staff, and a subset of outside experts from the first three workshops were invited to attend the LAW workshop. The purpose of the workshop was to reorganize and prioritize vital signs from earlier workshops and link terrestrial, aquatic (freshwater, brackish, and near-shore), and air quality vital signs.

Although ARCN's monitoring plan will not focus directly on large scale monitoring of atmospheric or oceanic systems, we recognize the importance of such influences on ARCN's terrestrial, coastal-influenced, and freshwater ecosystems. This workshop gave participants from each of the first three workshops a chance to discuss seemingly disparate vital signs in a more holistic fashion. One of the outcomes from this workshop was the realization that many of ARCN's vital signs cross typical ecosystem boundaries.

Water and air quality monitoring will be key components of ARCN's monitoring plan. Although the network foresees the National Park Service's Air Resources Division (ARD) taking the lead on air quality issues in the region, ARCN hopes to work closely with ARD staff. Although there are no Class 1 Areas as designated by Section 162(a) of the federal Clean Air Act in ARCN, air quality is still a major concern for these parks. Although ARD has recently dismantled the Interagency Air Quality Network Site from Ambler, Alaska, because air quality measurements were not being collected consistently by site operators, the network is currently trying to help ARD find a suitable location for relocation near the ARCN parks. Once installed, this air quality station would be equipped with sampling apparatus for four air quality monitoring networks: (1) Interagency Monitoring of Protected Visual Environments (IMPROVE); (2) National Atmospheric Deposition Program; (3) Clean Air Status and Trends Network (CASTNet); and (4) the Mercury Deposition Network. In addition, ARD initiated the ongoing Western Airborne Contaminants Assessment Project (WACAP) in 2003 to determine the risk to ecosystems and food webs in western national parks from the long-range transport of airborne contaminants.

The role of water quality monitoring in an integrated ecosystem context, Water Resources Division (WRD) core variables, and other water quality parameters were discussed at the coastal, freshwater, and LAW workshops. The network's strategy for water quality monitoring (funded by the NPS WRD) is to fully integrate the design and implementation of water quality monitoring with the network-based vital signs monitoring (see Chapter 3). To this end, ARCN plans to take a holistic approach in monitoring lakes, streams, and lagoons. Steps taken toward developing a water quality monitoring component of the plan include (1) identifying and evaluating existing monitoring efforts, historic data, and information needs; (2) developing a list of biological, chemical, and physical parameters for monitoring; and (3) determining watershed and larger landscape features of interest to the network. As part of these efforts, the network has determined that no 303(d) waters are present in any of the parks, however ARCN parklands do support seven Wild and Scenic Rivers, totaling just over 790 river miles (see section 1.12.8).

1.8 Superintendent Interviews

Input from park managers is critical to the success of the ARCN long-term monitoring program. In order to help facilitate the process of gathering information on natural resources of concern in the park units, we set up interviews with current and past superintendents of the five arctic parklands. Personal interviews with each of the current superintendents were conducted during 2005. Because of the high turnover in superintendents in four of the five park units, we also interviewed past superintendents who were accessible (i.e., still living and still working for NPS).

We asked each superintendent 10 questions that we felt would help us better understand the current and future challenges facing the management of their parklands and how best to make the ARCN monitoring program relevant to their park(s) (Appendix 1).

1.9 Regional Integration Among Networks: Landscape-Scale Collaboration

Because Alaska parks present unique challenges, regional collaboration is of the utmost importance. It will enable an integrated approach to better use science results and management resources. For example, because many of the Alaska parks occupy large land areas, have little or no resource staff, and are logistically difficult to monitor, it may be useful to adopt statistically rigorous sampling designs from another networks, share staff and expertise, or adopt successful protocols. In some cases, working with the same collaborators and resource staff will facilitate the larger scale contribution that the I&M Program can make to monitoring in Alaska.

1.10 Collaboration with the Other 31 Networks

The I&M Program is a national effort that is divided geographically and ecologically into many networks. This approach is needed not only for funding allocation and to attend to nationwide park management concerns, but also to ensure that, at the network level, high-priority local management concerns are addressed as effectively as national ones. It will be critical for ARCN to work closely with other networks to ensure that monitoring products integrate well at the national level, and that cross-network comparisons are valid and responsive to management needs. There are numerous databases, information resources, templates, and examples from preceding networks that are available through the national and regional offices that will be of great value in guiding the development of ARCN. We expect to use the expertise and learning experiences of the national and regional offices and the other four networks in Alaska as our program matures.

1.11 Park-Specific Legislative Mandates

All of the NPS units within the ARCN parks are relatively recent additions to the National Park System. Bering Land Bridge National Preserve was established by ANILCA on December 2, 1980. Section 202 (2) states:

> *Bering Land Bridge National Preserve shall be managed for the following purposes, among others: To protect and interpret examples of arctic plant communities, volcanic lava flows, ash explosions, coastal formations, and other geologic processes; to protect habitat for internation-*

ally significant populations of migratory birds; to provide for archeological and paleontological study, in cooperation with Native Alaskans, of the process of plant and animal migration, including man, between North America and the Asian Continent; to protect habitat for, and populations of, fish and wildlife including, but not limited to, marine mammals, brown/grizzly bears, moose, and wolves; subject to such reasonable regulations as the Secretary may prescribe, to continue reindeer grazing use, including necessary facilities and equipment, within the areas which on January 1, 1976, were subject to reindeer grazing permits, in accordance with sound range management practices; to protect the viability of subsistence resources; and in a manner consistent with the foregoing, to provide for outdoor recreation and environmental education activities including public access for recreational purposes to the Serpentine Hot Springs area. The Secretary shall permit the continuation of customary patterns and modes of travel during periods of adequate snow cover within a one-hundred-foot right-of-way along either side of an existing route from Deering to the Taylor Highway, subject to such reasonable regulations as the Secretary may promulgate to assure that such travel is consistent with the foregoing purposes.

Cape Krusenstern National Monument was established in 1978 by presidential proclamation and then designated in 1980 by ANILCA(16 USC 3101). Section 201(3) of ANILCA specifies:

The monument shall be managed for the following purposes, among others: To protect and interpret a series of archeological sites depicting every known cultural period in arctic Alaska; to provide for scientific study of the process of human population of the area from the Asian Continent; in cooperation with Native Alaskans, to preserve and interpret evidence of prehistoric and historic Native cultures; to protect habitat for seals and other marine mammals; to protect habitat for and populations of birds and other wildlife and fish resources; and to protect the viability of subsistence resources. Subsistence uses by local residents shall be permitted in the monument in accordance with the provisions of Title VIII [of ANILCA].

Gates of the Arctic National Park and Preserve was also established by ANILCA. Section 201(4)(a) directs:

The park and preserve shall be managed for the following purposes, among others: To maintain the wild and undeveloped character of the area, including opportunities for visitors to experience solitude, and natural environmental integrity and scenic beauty of the mountains, forelands, rivers, lakes, and other natural features; to provide continued opportunities, including reasonable access, for mountain climbing, mountaineering, and other wilderness recreational activities; and to protect habitat for and the populations of, fish and wildlife, including, but not limited to, caribou, grizzly bears, Dall's sheep, moose, wolves, and raptorial birds. Subsistence uses by local residents shall be permitted in the park, where such uses are traditional, in accordance with the provisions of title VIII.

Kobuk Valley National Park was established by ANILCA. Section 201(6) of this act states:

Kobuk Valley National Park shall be managed for the following purposes, among others: To maintain the environmental integrity of the natural features of the Kobuk River Valley, including the Kobuk, Salmon, and other rivers, the boreal forest, and the Great Kobuk Sand Dunes, in an undeveloped state; to protect and interpret, in cooperation with Native Alaskans, archeological sites associated with Native cultures; to protect migration routes for the Arctic caribou herd; to protect habitat for, and populations of, fish and wildlife including but not limited to caribou, moose, black and grizzly bears, wolves, and waterfowl; and to protect the viability of subsistence *resources. Subsistence uses by local residents shall be permitted in the park in accordance with the provisions of title VIII. Except at such times when, and locations where, to do so would be inconsistent with the purposes of the park, the Secretary shall permit aircraft to continue to land at sites in the upper Salmon River watershed.*

Noatak National Monument was created by presidential proclamation in December 1978. On December 2, 1980, through the enactment of ANILCA, the monument became Noatak National Preserve. Section 201(8) of ANILCA specifies that:

The preserve shall be managed for the following purposes, among others: To maintain the environmental integrity of the Noatak River and adjacent uplands within the preserve in such a manner as to assure the continuation of geological and biological processes unimpaired by adverse human activity; to protect habitat for, and populations of, fish and wildlife, including but not limited to caribou, grizzly bears, Dall's sheep, moose, wolves, and for waterfowl, raptors, and other species of birds; to protect archeological resources; and in a manner consistent with the foregoing, to provide opportunities for scientific research. The Secretary may establish a board consisting of scientists and other experts in the field of arctic research in order to assist him in the encouragement and administration of research efforts within the preserve.

1.12 Overview of ARCN Ecosystems

The ARCN parks contain a broad array of the ecosystems typical of the subarctic (boreal forest or taiga), and arctic (tundra) biomes of northwestern North America. The boundary, or ecotone, between these two biomes is also represented in many different phases. Because these parks encompass large areas of mountainous terrain, including a major portion of the Brooks Range, they also include examples of virtually every type of alpine situation to be found in northern Alaska.

The nature of boreal and arctic ecosystems is often profoundly influenced by climate, especially whether and to what degree the climate is maritime or continental. The climate of the ARCN parks varies from the extreme continentality of interior Alaska to the more maritime coastal areas of the parks bordering the Chukchi Sea. However, this maritime climate is somewhat modified by the presence of pack ice, which minimizes the moderating effect of the sea during the six to nine months it is present. Thus winters, even in coastal areas, are intensely cold and have relatively moderate precipitation and snow cover.

The total area encompassed by the five parks that make up the ARCN is roughly 7,802,305 hectares (19.3 million acres), of which Bering Land Bridge National Preserve is 1,026,930 hectares (2,537,592 acres); Cape Krusenstern National Monument is 236,448 hectares (584,276 acres); Gates of the Arctic National Park and Preserve is 3,323,270 hectares (8,211,974 acres); Kobuk Valley National Park is 675,747 hectares (1,669,808 acres); and the Noatak National Preserve is 2,539,910 hectares (6,276,255 acres).

1.12.1 Climate

The climate of northwest Alaska is characterized by long, cold winters and cool, wet summers. The entire region receives continuous sunlight during the summer for at least 30 days. While the coastal area experiences a predominantly maritime climate, the interior area has a more continental climate, with greater seasonal variations in temperatures and precipitation. Mean summer temperatures for the northwest region range from ~ 0° C in the higher mountains to as high as 12° C in the Mission Lowlands. Mean winter temperatures for the region range between –17 and –28° C.

The coastal areas typically receive regular high winds. Mean monthly winds at Kotzebue are above 10 knots from September through April and blow from the east. Mean wind speeds are comparable during the summer months (average 10.5 knots) but are from the west. August and September are the windiest months, while the most extreme winds are associated with winter storms. Wind speeds are somewhat less in the interior than at the coast. Coastal and lower elevation areas in the southwest portion of the region receive approximately 25 cm of precipitation annually. Higher inland areas to the east receive 63 to 76 cm of moisture. Rainfall usually increases as the summer months progress, usually peaking in August. Annual snowfall ranges from 114 cm in the southwest to more than 250 cm at higher elevations in the east. Freeze-up of surface waters generally occurs from early to mid October, and breakup occurs in mid to late May.

The climate of the Seward Peninsula and Bering Land Bridge National Preserve shows both maritime and continental influences. When surrounding marine waters are ice-free (mid June to early November), temperatures are moderate, humidity is high, and skies are typically cloudy, especially near the coast. Interior sections, even during this summer period, are somewhat drier and less cloudy and therefore have greater heat buildup during daytime hours and a greater daily temperature change. Summer is the wettest period, with perhaps 7 to 10 cm of the 25 cm of annual precipitation being recorded. Snow, with a relatively low water content, averages about 127 to 152 cm per year.

1.12.2 Geology

The national parks, preserves, and monuments of ARCN contain several very general components, including (a) most of the western half of Alaska's Brooks Range, (b) both hilly and low terrain on the northern Seward Peninsula, (c) broad lowlands draining major river systems approaching the coast of the Chukchi Sea, and (d) coastal lowlands and bluffs. Collectively, the processes responsible for the landforms, bedrock, and soils within ARCN are a complex suite spanning all three geologic eras, from the late Paleozoic to the present. Maritime, lacustrine, palustrine, lotic, aeolian, glacial, and volcanic/tectonic processes have all left prominent evidence of their influence throughout the ARCN region, with many interesting and often unique subtexts within each park unit.

Formation of major bedrock components spans much of earth's geologic history. The southern flank of the Brooks Range includes sedimentary rock dating to the late Precambrian Era, while the volcanic deposits on the Seward Peninsula date to as recently as 1,000 years ago. The Brooks Range itself is a collection of sub-ranges with igneous, sedimentary, and metamorphosed rocks added at different times, often through tectonic movement bringing terranes from distant origins. Different episodes of uplift, deformation, and intrusion have arranged the geologic substrata into several major synclines and anticlines with complex patterns of folding, fracturing, and thrust blocks. A comprehensive description of Brooks Range geology is a large report unto itself, but several noteworthy examples help to illustrate its essential character.

Much of the central Brooks Range is dominated by sedimentary deposits of Upper and Middle Devonian origin. These include limestone, sandstone, shale, siltstone, with occurrences of conglomerates, chert, and metamorphosed deposits. Notable formations include the Hunt Fork Shale, the Kanayut Conglomerate, the Eli Limestone, and the Nanook Limestone. This wide band of Devonian deposits stretches from the eastern border of Gates of the Arctic National Park and Preserve through the central portion of the Noatak National Preserve. Small but very prominent intrusive formations of early Cretaceous origin also occur within this area. The steep, jagged, and renowned Arrigetch Peaks are part of a granitic intrusion separating the Noatak and Alatna drainages within Gates of the Arctic.

Cape Krusenstern National Monument and the western edge of the Noatak National Preserve are dominated by similar sedimentary deposits of older Devonian and Silurian origin. Limestone, dolomite, phyllite, and chert are common components. Smaller pockets of these strata also occur within the Central Brooks Range. Notable formations include the Skajit Limestone.

The southern flank of the Brooks Range contains a collection of early Paleozoic and Precambrian deposits, including limestones, sandstones and shales along with siliceous and calcareous schists. This narrow band stretches from Kobuk Valley National Park east through the southern portions of Noatak National Preserve and Gates of the Arctic National Park and Preserve.

South of the Brooks Range in Kobuk Valley National Park, early and late Cretaceous sedimentary deposits underly later glacial and fluvial sediments in the broad Kobuk Valley. Shale, sandstone, siltstone, conglomerate, and greywacke dominate these deposits.

Geologic deposits in the uplands of Bering Land Bridge National Preserve are dominated by recent volcanic lava and ash flows dating from the Cretaceous-Tertiary boundary to the late Quaternary Period. Distinct lava flows around Imuruk Lake range in age from 65 million years (the Tertiary Kugruk volcanics) to as recently as 1,000 years (the Lost Jim flow). Older flows occurred on many separate occasions from a variety of vents and are now largely buried by the more recent flows as well as by wind-blown deposits of silt. Exposed volcanic rocks, all dark basaltic material, were originally rather smooth *pahoehoe* flows, with older flows subject to severe shattering by frost action into large angular fragments. Notable Cretaceous granitic intrusions also occur within these formations, with the tors surrounding Serpentine Hot Springs being the best known example.

1.12.3 Landforms and Soils

Landforms and soils within Arctic Network units are mainly products of glacial, fluvial, and Aeolian processes during the Cenozoic Era. Late Pleistocene glaciation exerts the most prominent, lasting influence throughout the region, having reshaped mountains formed by prior uplift, scoured broad valleys, and deposited boulder-to-silt-sized sediments through a variety of processes.

Higher peaks of Brooks Range mountains in GAAR are characterized by steep spires flanked by cirques and sharp arêtes as Pleistocene glaciers carved and transported bedrock downslope. Remnant ice left some higher areas dotted with depressions, creating small kettle lakes, while major glaciers gouged typical, broad, U-shaped valleys in what are now all of the major river drainages within ARCN. Many smaller mountains to the south and west through the Noatak National Preserve and Kobuk Valley National Park were overtopped by ice sheets and have a rounded or domelike profile with smooth saddles between peaks.

A suite of glacial deposits commonly line toe slopes and valley bottoms in the Brooks Range and its foothills. Kame terraces, recessional and lateral moraines, eskers, and outwash deposits are scattered throughout the region. Aeolian sand and silt deposits also occur intermingled with other features. Of particular interest are the dune features in Kobuk Valley National Park. Mostly formed during the previous Pleistocene interglacial and covering an area of roughly 90,000 hectares, they are now primarily vegetated, with the exception of the Great Kobuk, Little Kobuk, and Hunt River dunes, which are still active and cover about 8,300 hectares.

Post-glacial processes continue to modify the landscape as seasonal snow, ice, water, and wind continue to weather, transport, and redeposit substrates. Higher elevations typically grade from bedrock to fell fields and then talus moving downslope. Valley bottoms consist of fine sediments, sand, and gravel, redistributed as sinuous river systems carve new channels and abandon old ones. Mass wasting features are common on many hillslopes, some of which have been attributed to solifluction and gelifluction, possibly caused by intense summer rainfall events. Melting permafrost in the form of thermokarst and thaw lakes occurs in pockets in ARCN and may be caused by a combination of natural climatic and disturbance events.

Bering Land Bridge National Park and Cape Krusenstern National Monument are subject to coastal processes as well. Post-glacial isostatic rebounding and subsequent tidal forces shape much of the coast, leading to long, rocky, and gravelly bluffs and beach ridges. Cape Krusenstern is particularly known for the beach ridges made famous by the work of J. Louis Giddings, who described a chronosequence of prehistoric beach habitation in *The Archaeology of Cape Krusenstern*.

Large lagoon systems make up much of the rest of the coast, along with a few prominent river deltas such as the mouth of the Noatak River.

The north coast of the Seward Peninsula in Bering Land Bridge National Park is comprised of marine deposits from the late Pleistocene and Holocene epochs. Most of these sediments originate from the south and west coasts of the Seward Peninsula and are transported by prevailing currents in a continuing, progressive process of coastal erosion and redeposition that includes a highly dynamic series of low barrier islands.

Permafrost underlies much of the terrain within ARCN, sometimes within 10 cm of the surface. Pingos, ice wedges, patterned ground, thaw ponds, well-developed tussocks, and cryoturbation may be found primarily in and near valley bottoms throughout the region. Higher elevations and steeper slopes may or may not contain permafrost as frozen water by virtue of aspect (through summer insolation), grain size, drainage, and disturbance regime. Small snow fields and several small glaciers still exist within the region, primarily at higher elevations on north-facing slopes within Gates of the Arctic.

Soils within ARCN are diverse and range from thin layers of coarse-grained material to loamy, fine grained and organic deposits. Heavily vegetated areas usually contain a substantial layer of peat and semidecomposed organics atop frozen silt and gravel layers. Lowlands with a high density of lakes, estuaries, and freshwater wetlands, common in the western units, have deeper layers of fine-grained organic soils. Higher elevations are most commonly talus and sandy gravel, either exposed or covered by a thin layer of alpine tundra vegetation. Glacial and fluvial deposits near flowing water contain a mixture of grain sizes and are continually reorganized through hydrologic processes on streams and rivers.

1.12.4 Freshwater Resources of the Arctic Network

The ARCN parks have an extensive and diverse array of freshwater ecosystems that are relatively undisturbed by human activity. Key features of the landscape are the large freshwater lakes, seemingly endless miles of river networks, large expanses of wetlands, and unique isolated spring systems. There are seven wild and scenic rivers in the ARCN, including the Noatak, Salmon, Kobuk, Alatna, John, Tinayguk, and North Fork of the Koyukuk. All of the rivers of the ARCN are free-flowing and run clear most of the year. There are a few glacial streams that originate in the Brooks Range and several spring streams, including tributaries of the Reed River, Kugrak River, and Alatna River, although to date few studies have been conducted on them.

Much of the land within the ARCN is drained by streams that flow from the uplands into lowland areas, then empty into the Chukchi Sea or coastal lagoons. These lagoons have been a primary fishing ground for Native populations for the past 9,000 years. During the ice-free season, some of these streams and associated coastal lagoons provide important habitat for anadromous and freshwater fish populations, birds, and terrestrial mammals.

There are many lakes in the ARCN. Many of the large, deep lakes such as Chandler, Selby, Feniak, and Matcharak are renowned for their fisheries resources. These sites are heavily used by both subsistence and sport fishers. One of the largest, Walker Lake, was designated a national natural landmark in April 1968. Thousands of shallow lakes and wetlands are distributed throughout the parks. These ecosystems have diverse geologic origin, including countless thaw ponds, kettle lakes, maars, and oxbows that provide important rearing areas for fish, macroinvertebrates, and waterfowl.

There is little information on ground water in these parks, although some larger geothermal systems have been studied (e.g., Serpentine Hot Springs).

Freshwater Resources of the Bering Land Bridge National Preserve

Further study and classification of the freshwater resources within Bering Land Bridge National Preserve is needed. Two of the largest ecologically significant landscape features in BELA are Ikpek and Cowpack lagoons. These lagoons and the drainages that surround them are part of an important migratory shorebird and waterfowl resting and feeding area. The rivers and lagoons along this stretch of coast provide the only extensive system of barrier islands and sheltered water between the Arctic Ocean and the Yukon River delta. Consequently, migrating shorebirds and waterfowl use it extensively.

Extensive surface water is present in the northern half of the preserve, but the actual annual hydrologic budget is relatively small owing to the modest precipitation (25 to 38 cm). Five major rivers have substantial drainage basins within the boundary of the preserve, including the Serpentine, Cowpack, Nugnugaluktuk, Goodhope, and Noxapaga rivers. Others have only a small portion within or along the boundaries of the preserve. These include the Inmachuk, Kugruk, Koyuk, and Kuzitrin.

Serpentine Hot Springs is the main geothermal resource in the park. There are four areas along a 0.8 km reach of Hot Springs Creek where hot water discharge is visible. Discharge at the upper hot spring area (the location of the wooden bath area) is approximately 106 liters per second, with average temperatures ranging from 61 to 72° C (Roeder and Graham 1979). Discharge at the lower portion of the spring area is 146 liters per second. The surface water temperature has been measured at 15 to 21°C. There are also several small springs at Pilgrim Springs.

There is little basic information about fish diversity and distribution within BELA. The Alaska Natural Heritage Program identified 25 freshwater species with 9 documented (see Appendix 2). Information on fish presence in BELA appears to come mainly from reconnaissance-type trips to specific locations or from incidental observations by biologists working on other taxa. While there has been considerable work on freshwater and marine/coastal fish in the region by the Alaska Department of Fish and Game and others, very little of that work has occurred within the bounds of the preserve.

Freshwater Resources in Cape Krusenstern National Monument

The lands within CAKR are drained by a number of streams that flow from the uplands and empty into the Chukchi Sea or coastal lagoons. During the ice-free season, some of these streams and associated coastal lagoons provide important habitat for anadromous and freshwater fish populations, birds, and terrestrial mammals. During the winter, stream flow at the surface ceases as waters freeze. In areas where substantial springs exist, water may continue to flow out at the surface and then freeze into successive thin sheets of ice, forming aufeis areas. Both Jade and Rabbit creeks are subject to aufeis formation and have numerous channels and low intervening gravel bars.

Most of the streams in the monument are clearwater streams, exhibiting low levels of suspended solids, turbidity, and nutrients. Water is highly oxygenated, moderately hard to hard, and of the calcium bicarbonate type. At the Red Dog Mine site outside the monument, waters are naturally contaminated with cadmium, lead, and zinc. This contamination occurs because the ore in the ground is of sufficient quantity and concentration to alter the water as it passes over the ore deposit. There are several large lagoons and a few small lakes located within the monument. Ground water information for the monument is currently very scarce.

The Alaska Natural Heritage Program expected species list for freshwater and anadromous fish in the monument includes 24 species, 18 of which have been documented. Their list of marine fish includes 38 species, with only 8 species documented (Appendix 2).

Freshwater Resources in Gates of the Arctic National Park and Preserve

Tributaries of four major river systems originate in GAAR. To the north the Nigu, Killik, Chandler, Anaktuvuk, and Itkillik rivers drain to the Colville River. The Noatak River flows west and the Kobuk River southwest, both from headwaters in the western part of the park. The Reed and the Noatak rivers both start as glacial runoff from the flanks of Mount Igikpak. The John, Alatna, and North Fork of the Koyukuk rivers drain south to the Yukon River. Headwaters of six of the seven rivers that are designated as “Wild and Scenic” in ARCN are located in GAAR, including the Alatna, John, Kobuk, Noatak, North Fork of the Koyukuk, and Tinayguk rivers.

At least three “warm” springs are located within the park and preserve. The Reed River spring is located near the headwaters of the Reed and had a measured water temperature of 50°C at the warmest pool (NPS 1982). Spring sources are also located on the lower Kugrak and Alatna rivers.

The expected species list for the fishes of GAAR developed by the Alaska Natural Heritage Program includes 16 species, of which 14 have been documented (Appendix 2). The Kobuk and Koyukuk rivers are major chum salmon spawning streams. Sheefish also spawn in the Kobuk. These fish, along with whitefish, are the most important subsistence fishes. Some lake trout and arctic char are also taken from lakes for subsistence use. Recreational fishing is primarily for arctic grayling, arctic char, sheefish, and lake trout.

Freshwater Resources of Kobuk Valley National Park

The Kobuk and Noatak rivers are the largest rivers in northwest Alaska and together drain an area of 63,654 km^2. The Kobuk River drains 31,028 km^2 and has an estimated annual average flow of 438 m^3 per second. The river is 558 km long and 0.30 to 0.45 km wide in its lower and middle reaches. It is clear, except at the highest water stage, and has a generally sandy or gravelly bottom. The river is 50 m above sea level at the eastern boundary of Kobuk Valley National Park. Meander scrolls, oxbow bends, and sloughs are abundant along the river’s course. The floodplain of the Kobuk River varies from 1.6 to 12.8 km wide.

The major tributaries of the Kobuk River within the park boundary are the Kallarichuk, Salmon, Tutuksuk, Kaliguricheark, Hunt, and Akillik rivers. All have their headwaters in the Baird Mountains, and all are entirely undeveloped. The Salmon River and its surrounding watershed is 1,709 km and is a designated Wild and Scenic River. The Tutuksuk, east of the Salmon River, is 48 km long and drains 906 km^2. The Hunt River, in the eastern portion of the park, is 64 km long and drains 1,592 km^2.

Numerous small lakes and ponds lie in the Kobuk watershed, particularly in the lowlands along the river. Some ponds and lakes formed as detached oxbows of the meandering river, while others are thaw ponds, formed where permafrost has melted and caused depressions. Some small lakes of indeterminate origin lie on the north slopes of the Waring Mountains, and some true cirque lakes are found in the Baird Mountains.

Total dissolved solids in most streams in the region are generally less than 200 mg per liter. The Kobuk River at Kiana contains less than 250 mg per liter of dissolved solids. Magnesium and bicarbonate are most prevalent, while calcium and chloride are found in smaller quantities. Sediment loads are comparatively low; the free-flowing waters of northwest Alaska generally have the lowest yield of sediment in the state, due largely to low topographic relief, lack of glaciers, low levels of runoff, and the stabilizing effect of permafrost on soils.

The expected fish species list developed by the Alaska Natural Heritage Program includes 22 expected species, with 16 species documented (Appendix 2). A review of the available literature suggests that fish in KOVA are less well known than in NOAT. Most of the work has been conducted by the Alaska Department of Fish and Game relative to commercial and subsistence fisheries. The pre-ANILCA expedition of Melchior (1976) included some fish inventory work in KOVA.

Freshwater Ecosystems within the Noatak National Preserve

The Noatak National Preserve was, in part, created to maintain the environmental integrity of the Noatak River and adjacent uplands within the preserve to assure the continuation of geological and biological processes unimpaired by adverse human activity. The Noatak River and its surrounding watershed (3,035,200 ha) is also an internationally recognized Biosphere Reserve (UNESCO). The Noatak is the 11th largest river in Alaska in terms of the area it drains. Before flowing into Hotham Inlet of Kotzebue Sound, the river drains 32,600 km^2 and has an average annual flow of 309 m^3 per second. The main artery of the Noatak is 700 km long. Eleven relatively large streams, from 50 to 160 km long, are tributaries to the Noatak, as are 37 smaller streams. The Noatak River is a designated Wild and Scenic River.

Many lakes are within the Noatak watershed. Feniak Lake is the largest within the preserve boundary. Countless thaw ponds and potholes occur throughout the area, most as a result of permafrost that impedes the downward percolation of water that collects in depressions and thermokarst erosion, boosted by permafrost melting. Other ponds and lakes were formed as detached oxbows of the meandering river or developed as part of the extensive flat delta at the mouth of the Noatak River. Lake waters are generally lower in dissolved solids than river waters. Lowland surface waters, such as tundra lakes, however, are often characterized by a brownish color and are generally high in organic material. Approximately 22 species of fish are found within the Noatak drainage (Appendix 2).

1.12.5 Coastal Ecosystems of ARCN

Coastal ecosystems are a dominant feature within ARCN. Of the approximately 370 km (230 miles) of shoreline in ARCN, 120 km (75 miles) are in Cape Krusenstern National Monument and 250 km (155 miles) are in Bering Land Bridge National Preserve. The total shoreline, including bay and barrier island ecosystems surrounded by BELA, reaches approximately 450 km (280 miles). Together these parks make up the third largest block of coastline that the National Park Service manages (Figure 1.8).

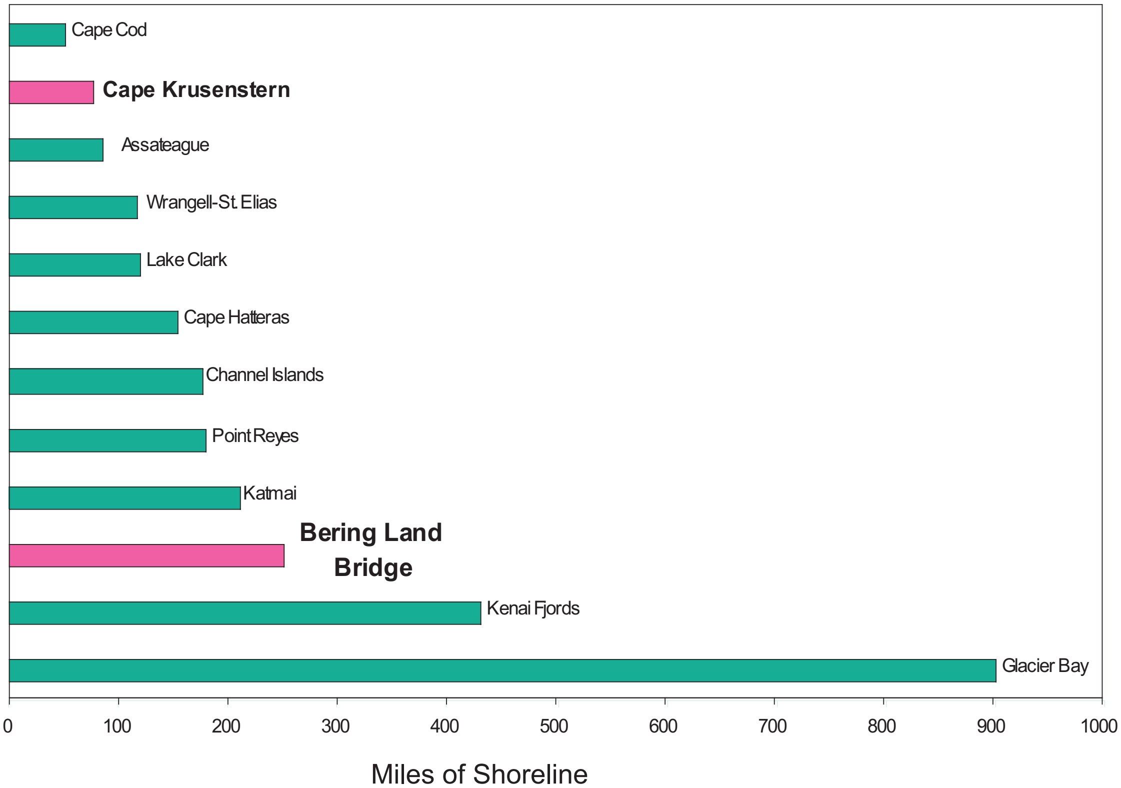


Figure 1.8. Miles of shoreline in ARCN in comparison to other NPS lands with coastal areas.

The coastal areas of ARCN have an extensive and diverse array of coastal ecosystems, which are relatively undisturbed by human activity. BELA and CAKR shorelines directly abut the Kotzebue Sound, Chukchi Sea, and Bering Strait; however, neither park includes the marine waters off-shore, since NPS boundaries end at the mean high tide mark. Important coastal ecosystems within CAKR and BELA include lagoons, estuaries, and islands as well as potential denning sites, seal haul-outs, and bird nesting and migratory stopover sites important for the marine mammals and birds of the adjacent coastal waters. In addition, both BELA and CAKR have explicit mandates in their establishing legislation for the protection of marine mammal habitat. The U.S. Fish and Wildlife Service (polar bears and walrus) and the National Marine Fisheries Service (seals and whales) oversee management of most marine mammal species in and around these coastal waters.

Near-shore coastal waters and shoreline ecosystems of importance to ARCN include intertidal and subtidal zones, salt-dominanted inlet systems, sandy shores, rocky cliffs, dune systems, and islands. Near-shore coastal waters have varying degrees of wave action and currents. Due to the almost constant exposure to wind and tidal currents, these ecological habitats are often more turbulent than lagoons or estuaries. Lagoon and estuarine ecosystems are common along the ARCN coastline. In fact, much of the land within the ARCN is drained by streams that flow from upland into lowland areas, then empty into the Chukchi Sea or coastal lagoons. There are five large coastal lagoons in CAKR, including Imak, Kotlik, Krusenstern, Ipiavik, and Akukulak lagoons. There are two large lagoons located in BELA: Ikpek and Cowpack. Several of these lagoons have been a primary fishing ground for Native populations for the past 9,000 years. During the ice-free season, some of these streams and associated coastal lagoons provide important habitat for anadromous and freshwater fish populations, birds, and terrestrial mammals.

Eelgrass beds (*Zostera marina* L.) have been documented as far north as Cape Espenberg in BELA (McRoy 1968), and incidental observations of eelgrass in CAKR have been officially noted over the last decade (McRoy, pers. comm.). These seagrass beds are primary habitat for many species of primary consumers (e.g., zooplankton) and fishes. The fauna of seagrass beds is often richer than areas not dominated by these habitats, due to the enhanced habitat and energy created by the presence of these beds.

The lagoons between Cape Krusenstern and Sheshalik are heavily used by migrating waterfowl. It is an important fall staging area for thousands of geese, ducks, shorebirds, and gulls. Seabird colonies are present in CAKR on Noatak Island (aleutian terns), at the Uhl-Williams site (aleutian and arctic terns), Krusenstern Lagoon (arctic terns and glaucus gulls), Kasik Lagoon (glaucus and mew gulls), and Tasaychek Lagoon (arctic and aleutian terns). In BELA, seabird colonies are located on the Sullivan Bluffs (glaucus gulls, black legged kittiwakes, and murres) and on two unnamed islands off the coast of Kongealoruk Creek (glaucus gulls) (Alaska Department of Fish and Game 1978). This area is also important for subsistence hunting of waterfowl and egg gathering.

Approximately 18 species of marine mammals use the waters of the Chukchi Sea and Kotzebue Sound, adjacent to CAKR and BELA (Table 1.2). Important marine mammal habitat within the park boundaries includes seal haul-out areas on the beaches of Cape Espenberg and the small islands southeast of Cape Espenberg.

Table 1.2. Marine mammal species present in the ocean adjacent to Bering Land Bridge National Preserve and Cape Krusenstern National Monument

Scientific Name	Common Name
Odobenus rosmarus	walrus
Eumetopias jubatus	Steller's sea lion
Callorhinus ursinus	northern fur seal
Erignathus barbatus	bearded seal
Phoca fasciata	ribbon seal
Phoca hispida	ringed seal
Phoca largha	spotted seal
Phoca vitulina	harbor seal
Phocoena phocoena	harbor porpoise
Ursus maritimus	polar bear
Balaena glacialis	right whale
Balaena mysticetus	bowhead whale
Balaenoptera acutorostrata	minke whale
Balaenoptera physalus	fin whale
Orcinus orca	killer whale
Eschrichtius robustus	gray whale
Delphinapterus leucas	beluga
Monodon monoceros	narwhale

Marine mammals are an important element in the subsistence lifestyle of many villages surrounding the park units; not only villages directly on the coast (such as Wales, Shishmaref, Kivalina, and Deering), but for inland villages as well (such as Noatak, Noorvik, Ambler, and Shungnak). Walrus (*Odobenus rosmarus*), bowhead whale (*Balaena mysticetus*), and bearded (*Erignathus barbatus*), ringed (*Phoca hispida*), and spotted seals (*Phoca largha*) are taken most often, but other whales, including beluga (*Delphinapterus leucas*), and seals are also found offshore. Although many of the harvested marine mammals do not actually spend much (or in some cases no) time on NPS lands, there are hunting camps and transportation routes within the parklands that are used in the traditional taking of these and other marine species. The harvest of all species of marine mammals is controlled under the

Marine Mammals Protection Act of 1972, which provides for subsistence harvest by Native Alaskans but forbids recreational hunting.

The ringed seal (*Phoca hispida*), the smallest of the northern seals, averages 70 kg and is found in the greatest densities off Cape Krusenstern in June. This seal is a life-sustaining species for people in the region, providing skin, meat, and oil. Traditional hunting of this species is concentrated off the coast of Cape Krusenstern at "Sealing Point." Bearded seals (*Erignathus barbatus*), the largest of the western arctic seals, weigh up to 360 kg. They are widely distributed in the Chukchi and Bering seas, where they feed on shrimp, benthic fish, clams, and worms. They appear in June in the waters adjacent to the monument. Despite the bearded seals' short seasonal presence, it is a highly important subsistence resource. Spotted seals (*Phoca largha*) and ribbon seals (*Phoca fasciata*) are also found off Cape Krusenstern. The spotted seal weighs up to 135 kg and feeds on herring (*Clupea pallasi*), salmon (*Oncorhynchus* spp.), and whitefish (*Coregonus* spp.) along the coast of the Chukchi Sea. The animals concentrate generally along the southern extent of ice pack. The ribbon seal (*Phoca fasciata*), with its distinctive white bands against a black body, is found in greatest abundance south and east of the Seward Peninsula in the central Bering Sea.

Walrus (*Odobenus rosmarus*) are uncommon off Cape Krusenstern, although stray animals and carcasses washed ashore are taken for their ivory, blubber, and meat, if usable.

Polar bears (*Ursus maritimus*) are found along the Chukchi Sea coast in winter, where they move into the area with the pack ice. Polar bears have been documented within the boundaries of BELA. These bears are thought to move with pack ice between Russia and the U.S.

Beluga whales (*Delphinapterus leucas*), which are small whales about 5 m long, occur throughout the Chukchi and Bering seas. These white whales travel in groups and are prized by subsistence hunters for their edible skin, blubber, and meat. A few beluga are taken from year to year along the monument's coastline when the shoreline becomes ice free or when they appear in open leads in the ice during sealing season (Uhl and Uhl 1980). Bowhead, gray, and finback whales have been observed within the waters of the Chukchi Sea off Cape Krusenstern.

1.12.6 Terrestrial Ecosystems of the Arctic Network

Terrestrial Vegetation

The most conspicuous feature of the vegetation in northwestern Alaska is treeline, or northward or coastward limit of conifer forests. The forest reaches its northwesternmost limit in North America in the vicinity of the eastern border of Cape Krusenstern National Monument and the western edge of the Noatak National Preserve (Young 1974) but treeline forms a complex and convoluted boundary through much of the three more eastern parks. A number of other organisms have ranges strongly associated with the presence of conifers: red squirrels, porcupines, certain typically understory plants, some tree-nesting birds, and some epiphytic lichens are examples.

Vascular Plants

Western and northwestern Alaska has long been recognized as having the richest array of vascular plants of any region in the circumpolar north (Hultén, 1937, 1968). This is due to a number of factors, the most important of which are as follows. First, the area was never totally glaciated during the later Pleistocene. This means that populations of many species of plants were presumably able to survive *in situ* throughout the period that most of the rest of northern North America was repeatedly glaciated (e.g., Hopkins et al. 1982). It also means that soil formation and various geological process that result in stable substrates have been going on uninterrupted for very long times in comparison to other North American areas, which have often been scoured to bare rock within the past 10,000 to 12,000 years. A second important factor is the location of the area at a place where many of the major mountain ranges of the world converge. The Brooks Range extends thousands of kilometers southward as part of the Rocky Mountains, while similar connected mountain ranges extend deep into central Asia. Thus, the Beringian region has probably long served as a "staging area" for alpine plants that are slowly colonizing the Arctic (Young 1971). Finally, the complex local topography and history of local glacial advance and retreat have created great variety in local habitats in terms of substrate, soils, microclimates, and disturbance.

There is currently little agreement or understanding of the responses of vascular plant vegetation to changing conditions, although this field is developing rapidly (e.g., Bradley 1999). Treeline and its advances and possible retreats has been an area of major interest since the mid 20th century, but the processes that influence the spread or retraction of the ranges of conifers are complex enough, and long-term enough, that the documentation and interpretation of changing treeline is still in its early stages. Much recent research deals with changes in nutrient regimes and the stability of various tundra plant communities. This line of investigation is very promising in terms of developing a theoretical framework and set of protocols for monitoring tundra ecosystems and interpreting their response to changing environmental factors (Chapin et al. 2000, Mack et al. 2004).

Many examples of areas of rare or unusual species and communities of vascular plants are known, and undoubtedly many more are to be discovered (see Appendix 3). An example would be the extensive serpentine barrens in the vicinity of Feniak Lake, in the middle Noatak drainage. This area actually contains a great variety of sub-sites with individual and unique arrays of plants.

Nonvascular Plants

Lichens and bryophytes are a conspicuous and ecologically important element in Alaska's arctic parks. Nonvascular plants are likely to represent 75 to 80% of ARCN's flora (Neitlich and Hasselbach 1998, NPFlora 1989). In many cover types, these plants constitute a co-dominant portion of the biomass (Viereck et al. 1992, Swanson et al. 1985) and account for a significant amount of cover in NPS's satellite imagery-based landcover maps (Markon and Wesser 1997, 1998, Swanson et al. 1985) and vegetation classifications (Nature Conservancy 1999, Viereck et al. 1992). Because of their fragility, ecological importance as forage, and high sensitivity to impacts from pollution (Pegau 1968, Nash 1988), the inventory and monitoring of lichens and bryophytes is a priority statewide. The ecological roles of Alaska arctic lichens and bryophytes include forage, nesting materials or direct shelter, nitrogen fixation, and primary productivity. Lichens serve as a major food source for many small and large mammals, including muskoxen, Dall's sheep, and ground squirrels (Sharnoff and Rosentreter 1998). An adult caribou typically consumes 5–6 kg/day of lichens during winter (Boertje 1984). Lichen consumers represent a major prey base for several top predators (e.g., wolves, bears, and owls). Lichens represent an exclusive food source for large numbers of arthropods (Gerson 1973) and contribute a small but significant quantity of fixed nitrogen to the region's nutrient-poor, low-productivity ecosystems (Gunther 1989).

Lichens are extremely fragile, slow-growing, and sensitive to air pollution (Richardson 1992). Different lichen species grow between 0.1 mm to about 5 mm per year. Because of slow growth and poor dispersal ability by lichens, attainment of late-successional terrestrial or epiphytic lichen communities can take up to 250 years in boreal and arctic environments (Black and Bliss 1978, Christiansen 1988). Lichens rely entirely on atmospheric inputs of water and nutrients for growth and have evolved to uptake atmospheric inputs readily without barriers of specialized tissue. Because of this, they are extremely susceptible to injury by S and N-based pollutants and acidification (Richardson 1992, McCune 1988). For this same reason, they are also reliable as passive monitors of contaminant accumulation via elemental analysis of tissue (Ford and Vlasova 1996).

Fire Regimes of the Arctic Network

Climate, terrain, and vegetation strongly influence the occurrence and extent of fires within ARCN. The subarctic boreal forests and low arctic tundra biomes are subject to periodic fires. Over the last 50 years, greater than 1.2 million acres have burned within and around ARCN park units, with an annual average of 24,000 acres burned per year, 96% of which are caused by lightening (NPS Fire Records 1956-2005). The frequency and extent of the fires is variable within the park units (Table 1.3). Fires can exert landscape-scale controls on vegetation structure and composition, permafrost dynamics, nutrient cycling, carbon loss/gain, primary productivity, and biodiversity (Racine et al. 2004).

Table 1.3. Acreage burned in and around ARCN from 1956–2005. Data includes all fires that have started within the park units, although not all acres are contained within the administrative boundary of the units. Fire information is based on NPS fire records.

	BELA	CAKR	GAAR	KOVA	NOAT	Total ARCN
Total Acres	289,670	4,285	314,215	202,158	430,405	1,240,732
Average acres/yr	5,793	86	6,284	4,043	8,608	24,815
Total # fires	36	5	145	60	135	364
Average # fires/yr	0.7	0.1	2.9	1.2	2.7	
Average fire size (acres)	7,828	857	2,228	3,485	3,188	

The southern third of GAAR lies within the northernmost belt of Interior Alaska, and has the greatest number of fire starts within ARCN. GAAR is on the periphery of interior weather patterns and is occasionally subject to large lightning bursts, associated with low precipitation and high temperatures in June and July. The spruce lichen woodlands, black spruce feather moss and low shrub-tussock tundra types south of the Brooks Range are the most common fuel types burned, with an estimated fire return interval of 100 to 200 years. Fires are infrequent in the northernmost two-thirds of GAAR due to the lack of fuels associated with the barren or sparse alpine tundra on the Brooks Range and the increased precipitation from the arctic coastal influence of the North Slope.

The lowlands of the Noatak Valley are subject to periodic large fires and frequent small fires from late May until early August. Fires commonly occur in shrub-tussock tundra, sedge/graminoid lowlands, and shrub thickets of dwarf birch/ericaceous, alder (*Alnus crispa*) or willow (*Salix* spp). More than 95% of Noatak's fires are caused by lightning. Thunderstorm development in the valley can result from synoptic widespread storms or localized air-mass storms controlled by local topography. Warm dry air masses within the Noatak Valley can encounter coastal low pressure systems from the west, leading to significant thunder cell development and lightning. When ignitions are accompanied by dry windy conditions, fires in the shrub-tussock tundra and low shrub birch/ericaceous can spread rapidly and burn thousands of acres in a few days.

KOVA is in the transition zone between the interior Alaska forests and northern and western tundra. Fires are most frequent in dryer areas south of the Baird Mountains within open and woodland spruce forests. The greatest number of starts occurs during June. As is typical of boreal forest fires, the fires tend to have longer duration than tundra fires.

The number of fires in CAKN and BELA are much lower due to the wet maritime conditions and lack of ignition sources. Only five fires have been detected in CAKR over the past 50 years. No fires have been recorded in the low wetlands of BELA. Inland from the coast, vegetation communities are subject to occasional fires. These vegetation communities are susceptible to fire, but low frequency of lightning (Dissing and Verbyla 2003) or higher precipitation reduces the number of ignitions within BELA. The majority of acres burned within the preserve occurred during 1977, in which several large fires burned within and around the Preserve. Over the past half century, fire suppression activity on the Seward Peninsula has possibly reduced the number of acres burned in the eastern half of BELA.

Birds of the Arctic Network

Most birds found in the ARCN are summer nesters or migrants, with only about a dozen species overwintering within the network. There is evidence supporting the presence of 177 bird species in ARCN, with individual parks containing between 114 and 132 species (Appendix 4) and as many as 12 to 26 species that have yet to be documented in one or more of the parks (NPSpecies 2004). A certified species list with citations is available, following the completion of final reports of the bird inventory efforts and the quality assurance/quality control process for the NPSpecies database.

Prior to current efforts, the ARCN was largely unsurveyed, leaving a gap in our knowledge of the breeding distribution and habitat requirements of many migrant and resident bird species. Fieldwork for a three-year montane-nesting bird inventory of the network was completed in 2003, with data analysis and final report compilation occurring in 2005. In addition, I&M and the Park Flight Program recently provided support for bird inventories within GAAR for a three-year landbird inventory scheduled for completion in 2005.

The northwest Alaska region provides important bird habitat because it is a major breeding area for migratory birds from as far away as Antarctica. This region encompasses a zone of interchange between the flyways of Asia and North America, and it includes important transitional habitat areas between boreal forest, coastal lands, and tundra.

More than 25 species of waterfowl inhabit the network's wetland areas. All four loon species are found in the Noatak drainage. The lagoons between Cape Krusenstern and Sheshalik are heavily used by migrating waterbirds. This area is also an important subsistence hunting area for waterfowl and as an egg gathering area. It is an important fall staging area for thousands of geese, ducks, shorebirds, and gulls. Prime waterfowl nesting areas also occur in the extensive wet lowlands in the Kobuk Valley. In BELA and CAKR, the marine/estuarine habitat, together with extensive freshwater ponds and lakes, provides resting, nesting, feeding, and molting grounds for large populations of migrating geese, ducks, and shorebirds. The salty grasslands and marshes at the mouths of the Nugnugaluktuk, Pish, and Goodhope rivers and Cape Espenberg are especially important for waterfowl adapted to estuarine conditions.

Raptors find important habitat within the Noatak drainage. Thirteen species of raptors are known in the preserve, and GAAR provides montane nesting habitat for numerous species with breeding ranges limited to Alaska, such as the surfbird and Smith's longspur (Tibbitts et al. 2003).

Of special interest among the remaining birdlife are several Asian species that have extended their ranges into North America along the Bering Land Bridge corridor. These include the wheatear, yellow wagtail, white wagtail, bluethroat, and arctic warbler (Young 1974).

Mammals of the Arctic Network

Approximately 42 species of terrestrial mammals are believed to occur within the boundaries of ARCN (Appendix 5), ranging in size from the tiny shrew (*Sorex yukonicus*) to brown bears (*Ursus arctos*) and moose (*Alces alces*). A certified species list with citations is available, following the completion of final reports of the mammal inventory efforts and the quality assurance/quality control process for the NPSpecies database.

Many northern mammal populations, such as lynx (*Lynx canadensis*), snowshoe hare (*Lepus americanus*), caribou (*Rangifer tarandus*), and lemmings (*Dicrostonyx* spp. and *Lemmus* spp.), are characterized by local, seasonal, or cyclic abundance. Distribution and abundance data are almost nonexistent except for animals hunted for subsistence.

Distributions of northern mammals are changing within historic times, such as the expansion of moose into the western Brooks Range within the last 70 years (Coady 1980) and the extirpation of muskoxen in the mid 19th century and their subsequent reintroduction during the 1970s (Lent 1999). Other species that have recently expanded their ranges north and west into one or more of the arctic park units include beaver and coyotes. Other large changes in populations include the 50 to 70% decline in the GAAR sheep population in the late 1980s, the 70% decline in moose on the drainages on the north side of the Brooks Range in the early 1990s, and the six-fold increase in the Western Arctic caribou herd during the last 25 years (75,000 animals in 1976 to 450,000 in 1999).

Ecological and distribution information about northern mammals is scant compared to that of parks in the contiguous U.S., where small changes in species' ranges are being tracked at a fine scale as species move north and up in altitude, in a possible response to global climate change (Burns et al. 2003). Recent I&M field inventories have demonstrated the paucity of knowledge of even the presence of the few species in the Arctic by providing vouchers for 12 mammal species not previously documented in one or more of the ARCN parks. By park unit, the number of new mammal species documented during inventory fieldwork from 2001 to 2003 were five in GAAR, two in NOAT, eight in KOVA, four in BELA, and six in CAKR. Additional literature searches have located more obscure documentation of an additional 10 species that were not previously thought present in one or more of the ARCN parks. Overall, recent efforts have increased the number of mammal species known to be present in ARCN parks by 19.

Some of the more notable species documented for the first time in one or more of the parks include the tiny shrew (*Sorex yukonicus*) which was newly discovered in GAAR, KOVA, BELA, and CAKR; the pygmy shrew (*S. hoyi*) newly documented in KOVA and CAKR, resulting in a known range extension of approximately 250 kilometers; the barren ground shrew (*S. ugyunak*) discovered in GAAR, BELA, CAKR, and NOAT (previously only documented on the North Slope, these new vouchers resulted in a known range extension of 300 kilometers south); the taiga vole (*Microtus xanthognathus*) in KOVA and NOAT (new vouchers resulting in a 150-kilometer known range extension to the northwest); and the porcupine (*Erethizon dorsatum*) in GAAR, of which few vouchers exist anywhere in the Brooks Range.

Among documented species, large data gaps and questions remain. For example, very few vouchers exist for marmots in Alaska, especially in the Arctic, where it is thought there may be two separate species: the Alaskan marmot and hoary marmot (*Marmota broweri* and *M. caligata* respectively).

Physical differences between these two species are so slight and understudied that no reliable published keys exist for identifying them. It is thought that the two species differ greatly in origin, with the Alaskan marmot being more closely related to Asian marmot species than to any North American marmot species (Olsen pers. comm.). A third species of marmot, the woodchuck (*M. monax*), has expanded its range from the Lower 48 as far north as Fairbanks during previous decades. Additional arctic and subarctic species that are thought to occur in the park but for which no documentation exists include pika (*Ochotona collaris*), bats (*Myotis* spp.), and the tundra hare (*Lepus othus*). Species thought to be expanding their ranges to interior Alaska from Canada include mountain lions (*Felis concolor*) and mule deer (*Odocoileus hemionus*). Range information and monitoring is thought to be especially important for Alaskan species in light of the more dramatic climate changes predicted for the region.

In addition to the terrestrial mammals, it is estimated that more than 13 species of marine mammals use the waters of the Chukchi Sea and Kotzebue Sound adjacent to Cape Krusenstern National Monument and Bering Land Bridge National Preserve. Both BELA and CAKR have mandates for the protection of marine mammal habitat (jurisdiction ends at the high-tide line). Polar bears and seals make dens or have haul-outs on the mainland, and many are frequently sighted in estuarine environments or small bays.

1.12.7 Records of Past Ecosystems and Events

ARCN contains exceptional opportunities for developing a picture of the events and processes that have resulted in the current array of ecosystems, both within the parks and preserves and in the circumpolar Arctic and boreal regions in general (Hopkins et al. 1982, Elias and Brigham-Grette 2000). The evidence ranges from large physical features, such as moraines and beach ridges, to long-term records of past environmental and climatic trends, such as sediment columns and animal fossils, to information derived from archaeological studies.

The importance of studies of this kind for our purposes is that they can establish a known trajectory for the direction and magnitude of ecosystem change and the processes that influence them over long periods of time. When information about the nature of modern ecosystems and the processes occurring within them can be evaluated in relation to long-term environmental changes—or stability— this can greatly increase our ability to discern their significance.

The main reason for this unusual richness of potential paleoenvironmental data is that much of the area was never glaciated during the Pleistocene and thus formed a part of unglaciated Beringia, as the eastern extension of the ancient Eurasian Arctic is often called. Other parts of ARCN were subject to only local glaciation, especially during the latter part of the Pleistocene. Also, some exceptional circumstances, such as the survival of ancient lake sediments at Imuruk Lake and the burial of ancient land surfaces under tephra, such as occurred on the northern Seward Peninsula, have created important opportunities for research.

The ARCN has been inhabited by humans for at least 12,000 to 13,000 years, and perhaps twice as long or even longer. There is abundant evidence for human activities for the past 4,000 to 5,000 years, and a major product of the study of these ancient cultures has been the accumulation of evidence for the nature of the environment in which these people lived. Archaeological studies are not only important in helping to document the role of prehistoric people in the local environment. They also often provide a rich source of data on aspects of the environment that are little affected by the presence of humans. For example, the spread of moose into northwestern Alaska in historic and late precontact times is largely known through the presence or absence of evidence for moose in well-documented archaeological sites throughout the area.

1.12.8 Summary of Unique Resources in ARCN

Unique Geomorphic and Ecological Features of ARCN

The Arctic Network contains many unique geomorphic and ecological features that are found in very few of the nation's national parks (Table 1.4). Permafrost, glaciers, granitic outcroppings, tors, pingos, taliks, springs, glacial-fed streams, coastal lagoons, large meandering rivers, maar lakes, lagoons, tundra lakes, and ponds are all parts of the northern Alaska landscape. A sampling of interesting features in ARCN parks includes the Lost Jim lava cone and other lava flows near Imuruk Lake, Serpentine Hot Springs, the coastal lagoons of BELA and CAKR, the sand dunes and Onion Portage in KOVA, and the Noatak River Watershed in GAAR and NOAT.

Table 1.4. Summary of unique resources in ARCN

Resource	BELA	CAKR	GAAR	KOVA	NOAT
Beach Ridges	x	x			
Biosphere Reserve					x
Hot Springs	x		x		
Lagoons	x	x			
Lava Beds	x				
Lava Cones	x				
Maar Lakes	x				
National Natural Landmarks			x		
Onion Portage				x	
Sand Dunes				x	
Subsistence Resources	x	x	x	x	x
Wild & Scenic Rivers			x	x	

National Natural Landmarks

The National Natural Landmarks Program recognizes and encourages the conservation of outstanding examples of our country's natural history. It is the only natural areas program of national scope that identifies and recognizes the best examples of biological and geological features in both public and private ownership. National Natural Landmarks are designated by the secretary of the interior. To date, fewer than 600 sites have been designated.

There are two official National Natural Landmarks in ARCN: Walker Lake and Arrigetch Peaks, both located in Gates of the Arctic National Park and Preserve.

- Walker Lake is a mountain lake at the northern limit of forest growth on the southern slope of the Brooks Range. Walker Lake was designated a National Natural Landmark in 1968.
- Arrigetch Peaks are located 70 miles west of Bettles in the Brooks Range and were designated a National Natural Landmark in 1968. Carved by glacial ice and running water, they illustrate several phases of alpine glacier activities. The peaks reveal abrupt transitions from metamorphic to granitic rock and contain both boreal forest and tundra ecosystems.

International Biosphere Reserve: The Noatak Watershed

In 1976 the United Nations Educational, Scientific, and Cultural Organization (UNESCO) Man and the Biosphere (MAB) Program designated the Noatak River and its surrounding watershed (more than 3,035,200 acres) as an international biosphere reserve. Biosphere reserves are chosen on the strength of their ability to reconcile the conservation of biological diversity and the sustainable use of biological resources. Biosphere reserves are nominated by member states after a process of consultation and coordination with government agencies, local communities, nongovernmental organizations, and private interests with a stake in the areas concerned. The advantages enjoyed by sites designated as biosphere reserves include official United Nations recognition of local and national efforts to promote conservation and sustainable development, a "label of excellence" that is helpful in securing additional funding, and membership in the World Network of Biosphere Reserves, which facilitates the exchange of ideas and scientific research results. The Noatak Biosphere Reserve was established to maintain the environmental integrity of the Noatak River and adjacent uplands, to protect wildlife habitats and populations, and to protect archaeological resources for scientific research.

Outstanding Natural Resource Waters in ARCN

Alaska has a general antidegradation policy for water bodies, but does not have procedures for designating Tier III waters or Outstanding Natural Resource Waters (ONWRs). There are seven Wild and Scenic Rivers in Alaska, which likely will be designated as ONRWs once the antidegradation policy implementation plan is approved.

Alaska's antidegradation policy is identical to federal law and can be found in 18 AAC 70.015. The policy states: (1) existing water uses and the level of water quality necessary to protect existing uses must be maintained and protected; (2) if the quality of a water exceeds levels necessary to support propagation of fish, shellfish, and wildlife and recreation in and on the water, that quality must be maintained and protected; (3) if a high-quality water constitutes an outstanding national resource, such as a water of a national or state park or wildlife refuge or a water of exceptional recreational or ecological significance, the quality of that water must be maintained and protected; and (4) if potential water quality impairment associated with a thermal discharge is involved, the antidegradation policy described in this section is subject to 33 USC 1326 (commonly known as Section 316 of the Clean Water Act).

According to the state, many water bodies have natural water quality that is better than the criteria set by the Water Quality Standards. In 1996 Alaska adopted the above antidegradation policy. However, the EPA also requires the state to develop an Antidegradation Policy Implementation Plan. The plan will specify the procedures and criteria used to determine when waters are degraded by point or nonpoint sources of pollution and what social and economic benefit to the state would be necessary to justify any degradation. The plan will also have procedures for nomination and designation of outstanding natural resource waters (ONRW). Alaska is in the process of developing this plan.

Wild and Scenic Rivers

Under the authority of the Wild and Scenic Rivers Act of 1968, Congress created the National Wild and Scenic Rivers System. In October 1968 the Wild and Scenic Rivers Act pronounced that "certain selected rivers of the Nation which, with their immediate environments, possess outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural or other similar values, shall be preserved in free-flowing condition, and that they and their immediate environments shall be protected for the benefit and enjoyment of present and future generations." Seven rivers in ARCN parks were designated as "wild" on December 2, 1980, under this act, including the Alatna, John, Kobuk, Noatak, North Fork Koyukuk, Salmon, and Tinayguk rivers. Wild river areas are defined as those rivers or sections of rivers that are free of impoundments and generally inaccessible except by trail, with watersheds or shorelines essentially primitive and waters unpolluted. The Alatna River (83 miles or 133 km) and North Fork Koyukuk (102 miles or 163 km), which are wholly within Gates of the Arctic National Park and Preserve, are designated as "wild" for their entirety. The 52-mile (83 km) segment of the John River within Gates of the Arctic National Park and Preserve is designated as "wild." From its headwaters in the Endicott Mountains and Walker Lake in Gates of the Arctic National Park and Preserve, the Kobuk River is also designated as "wild" (110 miles or 160 km). The Noatak River from its source in Gates of the Arctic National Park and Preserve to the Kelly River in the Noatak National Preserve (330 total miles or 528 km) is designated as "wild." The Salmon River within the Kobuk Valley National Park (70 miles or 112 km), and the Tinayguk River in Gates of the Arctic National Park and Preserve (44 miles or 70 km) are also designated as "wild."

1.13 Potential Resource Concerns for ARCN

The national program has created a NPS Ecological Monitoring Framework that is a systems-based, hierarchical, organizational tool for promoting communication, collaboration, and coordination among parks, networks, programs, and agencies involved in ecological monitoring.

Networks embarking on selecting vital signs (Phase 2) and protocol development (Phase 3) of those vital signs are using this framework for assigning vital signs to the Level 3 category. Since ARCN has not yet selected its vital signs, we are using this framework to show potential resource concerns for each of the parks (Table 1.5). It is our hope that by organizing our thoughts into the national framework early in designing our monitoring program, we will facilitate collaboration among networks.

Issues of concern for resource management in the ARCN parklands are myriad. The arctic is a harsh environment with wide variety in physical extremes, including day lengths and temperatures that vary dramatically by season. Conditions of low precipitation, perpetually frozen soils, low biodiversity, and relatively simple, though idiosyncratic, habitat systems abound among varied landscapes, including tundra estuaries, beaches, lagoons, dunes, thick boreal forests, shrublands, and extensive wetlands.

While most national parklands do not allow consumptive use of their resources, ARCN is different. The enabling legislation for these parks accommodates the continuing tradition of subsistence use of resources by neighboring communities. People have been harvesting game and fish from areas in and around the parks for thousands of years. With the acquisition of the parks came the responsibility to maintain these subsistence resources in good condition. Accomplishing this task will require monitoring the population ecology of subsistence animals in order to provide accurate baseline information to managers.

Pollution is also a concern in the Arctic. The seemingly pristine appearance of the region belies the fact that it is unceasingly bombarded by pollutants from both local and global industry. Arctic haze, contamination by persistent organic pollutants (POPs) and heavy metals, and condensation and bioaccumulation of pollutants are also issues of management concern for arctic parks.

Climatic stressors may be the foremost issues that park management will deal with. Models indicate that subtle climate changes will have the most dramatic effect in arctic regions. These changes will be observable in many attributes of the arctic system, including thermokarst dynamics, thaw lakes, active layer depth, snowpack persistence, variations in timing of wildlife migrations, plant phenology, greenup, treeline dynamics, albedo, and sea ice extent and duration. Of all known arctic ecosystem

Table 1.5. Potential resource concerns in the context of the National Ecological Monitoring Framework (X indicates a potential resource concern for the park, preserve or monument, – indicates low likelihood of a resource concern for the park, preserve or monument). Specific concerns of high pertinence to the Arctic Network are listed in the last column.

National Ecological Monitoring Framework			Potential Resource Concerns					Major Specific Concerns
Level 1 Category	**Level 2 Category**	**Level 3 Category**	**BELA**	**CAKR**	**GAAR**	**KOVA**	**NOAT**	**Any or All Parks**
Air and Climate	Air Quality	Ozone	–	–	–	–	–	–
		Wet and Dry Deposition	X	X	X	X	X	POPs, Metals, Nitrates, Sulfates
		Visibility and Particulate Matter	X	X	X	X	X	Arctic Haze
		Air Contaminants	X	X	X	X	X	Arctic Haze
	Weather and Climate	Weather and Climate (Climate Change)	X	X	X	X	X	Climate Change
Geology and Soils	Geomorphology	Windblown Features and Processes	X	X	X	X	X	Kobuk Dunes Ecosystem
		Glacial Features and Processes	–	–	X	–	X	Glacier Dynamics
		Hillslope Features and Processes	X	X	X	X	X	Erosion, Solifluction
		Coastal/ Oceanographic Features and Processes	X	X	–	–	–	Sea Ice
		Marine Features and Processes	X	X	–	–	–	Prevailing Currents, Marine–derived Food Sources
		Stream/River Channel Characteristics	X	X	X	X	X	
		Lake Features and Processes	X	X	X	X	X	Thermokarst, Drainage, Eutrophication, Water Quality
	Subsurface Geologic Processes	Geothermal Features and Processes	X	–	X	–	–	Unique Microhabitats, Human Use/ Development
		Cave/Karst Features and Processes	–	–	–	–	–	
		Volcanic Features and Processes	–	–	–	–	–	
		Seismic Activity	–	–	–	–	–	
	Soil Quality	Soil Function and Dynamics	X	X	X	X	X	Thermokarst, Nutrient Cycling/ Sequestration
	Paleontology	Paleontology	X	X	X	X	X	Paleoresource Protection

(continued on next page)

Table 1.5 (continued)

National Ecological Monitoring Framework			Potential Resource Concerns					Major Specific Concerns
Level 1 Category	**Level 2 Category**	**Level 3 Category**	**BELA**	**CAKR**	**GAAR**	**KOVA**	**NOAT**	**Any or All Parks**
Water	Hydrology	Groundwater Dynamics	X	X	X	X	X	Permafrost, Groundwater Dynamics
		Surface Water Dynamics	X	X	X	X	X	Permafrost, Surface Water Dynamics
		Marine Hydrology	X	X				
	Water Quality	Water Chemistry	X	X	X	X	X	Eutrophication, Water Quality
		Nutrient Dynamics	X	X	X	X	X	Nutrient Dynamics
		Toxics	–	X	–	–	X	Pollution, Human Waste/Chemical Spills
		Microorganisms	X	X	X	X	X	
		Aquatic Macroinvertebrates and Algae	X	X	X	X	X	
Biological Integrity	Invasive Species	Invasive/Exotic Plants	X	X	X	X	X	
		Invasive/Exotic Animals	–	–	–	–	–	
	Infestations and Disease	Insect Pests	X	X	X	X	X	Spruce Beetle, Defoliators
		Plant Diseases	X	X	X	X	X	Vectors, Transmission Mechanics, Outbreaks
		Animal Diseases	X	X	X	X	X	Avian Flu, Pneumonia, Lice, Pasteurellosis, Johanssen's Disease, Brucellosis, etc.
	Focal Species or Communities	Marine Communities	–	–	–	–	–	
		Intertidal Communities	X	X	–	–	–	
		Estuarine Communities	X	X	–	–	–	
		Wetland Communities	X	X	X	X	X	Lagoon Ecology
		Riparian Communities	X	X	X	X	X	
		Freshwater Communities	X	X	X	X	X	
		Sparsely Vegetated Communities	X	X	X	X	X	Rare, unique microhabitats, distribution/area
		Cave Communities	–	–	–	–	–	
		Desert Communities	–	–	–	–	–	
		Grassland/ Herbaceous Communities	X	X	X	X	X	

(continued on next page)

Table 1.5 (continued)

National Ecological Monitoring Framework			Potential Resource Concerns					Major Specific Concerns
Level 1 Category	**Level 2 Category**	**Level 3 Category**	**BELA**	**CAKR**	**GAAR**	**KOVA**	**NOAT**	**Any or All Parks**
		Shrubland Communities	X	X	X	X	X	
		Forest/Woodland Communities	X	–	X	X	X	
		Marine Invertebrates	–	–	–	–	–	
		Freshwater Invertebrates	X	X	X	X	X	
		Terrestrial Invertebrates	X	X	X	X	X	
		Fishes	X	X	X	X	X	Resident Fish, Subsistence
		Amphibians and Reptiles	–	–	–	–	–	
		Birds	X	X	X	X	X	
		Mammals	X	X	X	X	X	
		Vegetation Complex (use sparingly)	X	X	X	X	X	
		Terrestrial Complex (use sparingly)	X	X	X	X	X	
	At-risk Biota	T&E Species and Communities	X	X	X	X	X	
Human Use	Point Source Human Effects	Point Source Human Effects	X	X	X	X	X	Mining/Industrial Pollution, Human Waste, ATV, Trash
	Nonpoint Source Human Effects	Non-point Source Human Effects	X	X	X	X	X	Arctic Haze, Industrial Pollution, Bioaccumulation
	Consumptive Use	Consumptive Use	X	X	X	X	X	
	Visitor and Recreation Use	Visitor Use	X	X	X	X	X	
	Cultural Landscapes	Cultural Landscapes	X	X	X	X	X	
Landscapes (Ecosystem Pattern and Processes)	Fire and Fuel Dynamics	Fire and Fuel Dynamics	X	X	X	X	X	Habitat, Thermokarst
	Landscape Dynamics	Land Cover and Use	X	X	X	X	X	Development, NPRA, Coal, Oil, Mining, 2477 Roads, Treeline, Plant Community Distribution
	Extreme Disturbance Events	Extreme Disturbance Events	X	X	X	X	X	Fire, Coastal Erosion
	Soundscape	Soundscape	–	–	X	X	X	
	Viewscape	Viewscape/Dark Night Sky	–	–	–	–	–	
	Nutrient Dynamics	Nutrient Dynamics	X	X	X	X	X	Carbon Sequestration/ Release
	Energy Flow	Primary Production	X	X	X	X	X	

drivers, climate has the greatest potential to cause pronounced, cascading effects on arctic processes and subsystems.

Permafrost dynamics should figure prominently in any effort to monitor arctic ecosystems. Perennially frozen soils dictate land drainage complexity, vegetation assemblages, and mechanics of nutrient cycling and sequestration. Thermokarst, peat, water discharge, and soil hydrology are all affected by underlying soil characteristics and each of these in turn could have a profound influence on landscape-level plant community structure and habitat patterns.

Despite the physiognomic differences in each of the arctic parks, water plays a consistent and powerful role in each of them. From sea ice, coastal erosion, brackish lagoons, and estuaries along the coast to freshwater travel corridors, karst ponds, wetlands, permafrost, and glaciers in the interior, water ultimately sculpts the land and dictates the distribution and abundance of species. Water quality must remain high to maintain subsistence plants and animals in good condition, particularly fish species. Both legislators and park visitors demand that National Wild and Scenic Rivers have clean water, and our choices in vital signs must reflect water quality issues.

The effect of water on the environment is not limited to its chemical makeup. Water is also a powerful geophysical force, physically changing the landscape in dramatic ways. Shoreline erosion is becoming a severe issue to communities in the Bering Strait and Chukchi Sea and may adversely affect the stability of unique coastal habitats including lagoons, estuaries, and near-shore riverbanks. Thermokarst action and natural lake drainage continually change the face of certain landscapes. The net result of these processes is an ephemeral and dynamic system of water bodies that easily appear and disappear by draining, drying, slumping, and infilling. From a monitoring perspective it may be important to quantify the variability of these processes and to better understand their consequences to park resource values, particularly since they are demonstrably sensitive to climate trends.

Baseline inventories of water bodies and animal, microbial, and plant assemblages will be of particular interest to our monitoring program. Migration and breeding times and locations of animals, plant green-up, flowering and senescence are sensitive to environmental changes. In addition, exploitation of preexisting but unused rights-of-way for road construction may provide new mechanisms for dispersal of invasive and noxious species as well as increased human traffic and the accompanying mélange of detrimental effects. Finally, the sheer size of the parks provides for a large variety of very specialized microhabitats and associated rare species. These habitats and the viability and characteristics of their resident organisms should be inventoried and monitored to establish baseline information.

Subsistence and consumptive resource uses are allowed in many of the arctic parks and, consequently, add a layer of complexity to park management. Habitat quality and game and fish populations are important to local communities and must be managed, protected, and preserved. We expect that access to the parks will be improved over time and exploitation of these resources will need to be monitored. All-terrain vehicle use is increasing, particularly near remote communities, and these vehicles leave an indelibly detrimental mark on the landscape, in addition to disturbing wildlife and increasing pollution and trash dispersal.

Little specific information is available on the long-term impacts of human activities on the arctic ecosystem. Potentially quantifiable effects include trash buildup, pollution of many sorts, human waste, leaking fuel drums, petroleum spills, mining and industrial enterprises, hazardous dust, and the various impacts of oil and gas exploration. These issues will have to be prioritized and included in our monitoring plan.

One more focus area for the monitoring program is in landscape-level processes. The ecology of the arctic parks is dynamic and the functionality of the system is greatly affected by broad cycles and trends, both anthropogenically induced and natural. Fire is a common disturbance agent, influencing both forested river valleys and open tundra. Fire can significantly alter habitat, thaw permafrost, modify hydrological and successional patterns, and play a significant role in nutrient cycling.

Another major component driving the state of coastal park ecosystems is the timing, distribution, and duration of sea ice. Sea ice can have a large impact on predator-prey relationships of both sea and terrestrial mammals as well as on subsistence activities. Broad-scale climatic factors influencing the spatial arrangement of animals and plants include basic ranges of temperature and precipitation, but also feedback loops driven by prevailing weather patterns, cloudiness, and albedo.

A review of this very basic introduction to possible vital signs elucidates the challenges we face as we proceed into Phase 2 of our program. All the factors mentioned above may act in unique ways to augment potential anthropogenic threats to arctic ecosystems. The vital signs we select must be pertinent to management, sensitive to anthropogenic change, have a known or easily determined level of variance, and be inexpensive to measure and analyze. In light of these requirements and the vast array of possibilities, vital sign selection may well be the toughest step faced by the program.

1.14 Monitoring Objectives for ARCN

The overall goals of natural resource monitoring in the national parks are to develop scientifically sound information on the current status and long-term trends in the composition, structure, and function of park ecosystems and to determine how well current management practices are sustaining those ecosystems.

The monitoring program of ARCN will be designed around the five service-wide goals:

- Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
- Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
- Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.
- Provide data to meet certain legal and congressional mandates related to natural resource protection and visitor enjoyment.
- Provide a means of measuring progress towards performance goals.

Service-wide goals 1 and 3 establish the primary framework for monitoring in ARCN because they emphasize the following: (i) the establishment of baseline reference conditions representing the current status of park, preserve, and monument ecosystems; and (ii) an understanding of the range of natural variation in park ecosystems and detecting changes through time (Bennett et al. 2006).

In order to detect change at the landscape, ecosystem, community, or population scale, these five goals must be refined to more specific monitoring objectives (Table 1.6). What follows are potential overarching monitoring objectives for ARCN that were developed during the first three scoping workshops: the freshwater, coastal-influenced, and terrestrial workshops, and expanded later to more broad objectives (See Phase 1, Appendices 2, 4, and 6 for original list of objectives and detailed questions).

Table 1.6. General monitoring objectives and overarching themes for ARCN

Climate and Weather
Objective 1: Understand the natural variation in weather and climate patterns across ARCN using past and current data
Objective 2: Analyze current trends in climate and weather patterns
Objective 3: Predict future trends in climate and weather patterns in ARCN
Objective 4: Understand the natural variability in depth, phenology and distribution of snow and ice in ARCN
Objective 5: Determine how the extent, duration and timing of snow and ice cover are changing in the ARCN
Air Quality and the Deposition and Accumulation of Pollutants
Objective 1: Determine the main components of air pollution in ARCN
Objective 2: Determine if air quality is changing
Objective 3: Determine the contaminant levels in freshwater, coastal-influenced, and terrestrial ecosystems
Landscape Processes and Dynamics
Objective 1: Determine what large landscape-level changes are occurring
Objective 2: Understand the changes in volume and distribution of water
Objective 3: Determine the extent and distribution of thermokarsts
Objective 4: Determine changes in land cover and terrestrial vegetation composition and distribution across the landscape
Objective 5: Determine if migratory and invasive species are replacing native plants and animals
Freshwater Ecosystems: Freshwater Lakes and Wadeable Streams
Objective 1: Understand the patterns and long-term trends in the physical, chemical, and biological characteristics of streams, lakes, and surrounding watersheds
Objective 2: Understand how landscape components interact at various spatial and temporal scales to affect freshwater ecosystems
Coastal Ecosystems: Coastal Lagoons, Estuaries, Sandy beaches, Tundra Bluffs, and Rocky Shores
Objective 1: Understand the patterns and long-term trends in the physical, chemical, and biological characteristics of coastal lagoons, estuaries, sandy beaches, tundra bluffs, and rocky shores
Objective 2: Understand how landscape components interact at various spatial and temporal scales to affect arctic coastal ecosystems
Terrestrial Ecosystems: Tundra and Boreal Forest Ecosystems
Objective 1: Determine the status and long-term trends of vegetation and soils of tundra and boreal forest ecosystems within ARCN parklands
Objective 2: Determine the extent of treeline advance and shrub-line expansion due to accelerated climate change
Objective 3: Understand interactions between landscape components at various spatial and temporal scales and their effects on terrestrial ecosystems
Biological Diversity and Ecosystem Resilience
Objective 1: Document the rates and changes in biological diversity in terrestrial, aquatic, and coastal ecosystems
Objective 2: Understand the ecosystem consequences to shifts in biological diversity
Population Trends in Species of Interest
Objective 1: Determine the current abundance and distribution of selected species of interest
Objective 2: Monitor the productivity, recruitment, and mortality of selected species of interest
Objective 3: Understand the effects of human presence and development on selected species of interest
Consumptive Use of Resources
Objective 1: Understand the temporal and spatial trends in consumptive uses of mammals, birds, fishes, and plants in ARCN
Objective 2: Determine how local human populations are impacted by changes in subsistence resources

1.15 Summary of Past, Present, and Planned Future Monitoring Activities in ARCN

No task could be more important to developing a monitoring program than a thorough review of existing literature and prior inventory and monitoring efforts. The Arctic Network has made progress in assembling a knowledge base that will be valuable in designing a monitoring plan. Our data mining efforts have focused on two fronts: (1) assembling a natural resource bibliography and (2) identifying sources of high-quality inventory and monitoring data and collaborations. In 2004 we made great progress on populating NatureBib, the national Inventory and Monitoring bibliography, with publications about the arctic parks ecosystem. This effort has yielded thousands of references that will be a significant resource on the arctic biome. We also began data mining efforts with the goal of identifying present and historical resource inventories and monitoring efforts. While this effort is just getting started, we expect it will continue through the life of the program. Thus far, we have made a preliminary list of agencies, programs, existing ecological inventories, and long-term studies that may be of value to ARCN. This list is not exhaustive but highlights prominent, large-scale, and relevant data resources. The matrix in Table 1.7 also hints at significant data gaps for ARCN.

Details about the datasets used to generate the matrix in Table 1.7 are described in Appendix 7, including their administrative agency, website URL, data categories, level two vital sign designation, and a summary.

1.16 Summary of Joint Arctic Initiatives of Importance to ARCN

Much of the knowledge of how arctic terrestrial and aquatic ecosystems respond to change has been generated at large, long-term research stations that facilitate multi- and interdisciplinary science (e.g., Toolik Lake Long Term Ecological Research Site). As the Arctic continues to undergo dramatic changes in climate and human land use, there is a paramount need to further understand how arctic ecosystems outside these long-term research stations will be impacted and how these changes will influence the future state of the Arctic and Earth systems. Many integrated monitoring and research networks are already in place or under development throughout the Arctic. Throughout the last decade, there have been a number of major international research and monitoring initiatives of significance to ARCN. In order for ARCN to develop a successful monitoring program, participation in national and international initiatives will be of the utmost importance (e.g., International Polar Year, High Latitude Ecological Observatory Network or HLEO-NEON). Appendix 7 summarizes some of the most significant science initiatives taking place in the Arctic.

Table 1.7. Summary of counts of major inventory and monitoring efforts in ARCN

Category	BELA	CAKR	GAAR	KOVA	NOAT
Air Chemistry	1	1			
Amphibians	1	1	1	1	1
At-Risk Populations/Biota	1	1			
Baseline/Long-Term Plots					
Biodiversity	2	2	2	2	2
Biogeochemical Processes	1				
Birds	5	5	5	5	5
Climate/Weather/Climate Change	3	2	3	2	3
Contaminants	1	2			
Disease/Parasites	1	1	1	1	1
Disturbance/Fragmentation					
Fire	3	2	3	3	3
Fish	3	3	3	3	3
Food Webs/Trophic Interactions					
Fungi					
Geology	1	1			
Geomorphology/Landform Processes					
GIS datasets	1	1	1	1	1
Glacial Features and Processes					
Groundwater Dynamics					
Hillslope Features and Processes					
Human Use Activities (Subsistence)	1				
Ice Processes and Dynamics, Snow					
Invasive Species	1	1	1	1	1
Invertebrates					
Lagoons					
Lake Features & Processes	2	2	2	2	2
Land Use/Landcover Change	6	7	4	6	4
Large Mammals	4	5	5	4	5
Management Concern	3	3	2	2	2
Marine Features and Processes					
Marine Hydrology					
Marine Mammals					
Microorganisms/Microbes					
Non-Vascular Plants					
Nutrient Dynamics/Cycling					
Paleoecology and Paleontology					
Permafrost					
Phenology					
Primary Production					
Remote Sensing					
Small Mammals	3	3	3	3	3
Soils (Chemistry, Erosion)	1	3			
Stream/River Channel Characteristics	2	2	2	2	2
Surface Water Dynamics					
Vascular Plants	2	2	3	2	3
Vegetation (general)	3	4	3	3	3
Visitor Usage					
Water Quality/Biota/Chemistry	1	1	1	2	1
Wetland (Distribution and Abundance)	3	3	3	4	3
Windblown Features and Processes	1				

Chapter 2

Conceptual Models

"Everything should be made as simple as possible, but not one bit simpler."—Albert Einstein

2.1 Introduction: Framework for Conceptual Model Development

Conceptual ecosystem models are an excellent way to convey information about complex ecosystems to resource managers and the public. Conceptual models can also be used to help describe our current understanding of anthropogenic sources of disturbance to those ecosystems and the processes or components of the ecosystem impacted by that disturbance (Jenkins et al. 2003). Conceptual models should: (1) describe our current understanding of system components and processes, (2) identify linkages and interactions between those components, and (3) identify gaps in our knowledge (Gross 2003).

Early in the process of developing a monitoring program, visual models provide a framework for discussing the ecosystems of interest. While the National Park Service's Monitoring Program "does not intend to develop quantitative ecosystem models or dictate management policy, constructing a set of realistic, focused conceptual models is an important starting point for designing effective management policies" (Gross 2003). To this end, ARCN developed several 3-D landscape-scale ecosystem models that describe key features and processes within the ARCN parks. In some cases, additional descriptive models were developed in order to highlight unique ecosystems of interest (e.g., arctic lagoons, spring streams) and provide additional details about key ecosystem processes or components of interest. A series of nested models describing current and future threats to ARCN ecosystems and potential consequences of those threats is also presented. Special areas of management concern for ARCN parklands (e.g., global climate change, air toxins, invasive species) are also addressed using conceptual models.

2.2 The Arctic Network Strategy for Conceptual Model Development

The Arctic Network held three scoping workshops, which were designed, in part, to help network staff develop a set of conceptual models of the natural and anthropogenic features and processes of the enormous areas included in the parks. Each of the three workshops tackled one of three areas of interest to ARCN: freshwater, coastal-influenced, and terrestrial ecosystems. Workshop participants received a workshop notebook before each of the scoping workshops. Before attending the workshops, technical committee members and outside experts attending each of the meetings were asked to either create models in their area of expertise or comment on earlier versions of draft models. On day two of the workshops, participants split up into small working groups to further revise models. All hand-drawn draft models from each of the workshops were reproduced in a computer graphics program and placed in workshop output summary documents (see Phase 1 workshop appendices 4–6 at <http://www1.nature.nps.gov/im/units/arcn/documents/index.cfm>). Information from the workshops was then interpreted and summarized into 3-D landscape-scale conceptual ecosystem models. These models were included in the post-workshop output summary documents. The output documents were placed on the ARCN website for workshop participants to review. Models were revised where appropriate. A subset of these models appear in this chapter.

Our hope is that the models will (1) help to describe the complex ecosystems of ARCN, (2) elucidate current and potential drivers and anthropogenic stressors to ARCN ecosystems, (3) suggest potential mechanisms by which these anthropogenic stressors could impact ARCN ecosystems, and (4) help lay the foundation for monitoring critical aspects of the environment of the parks.

Just as ecosystems are fundamentally dynamic, so should be the conceptual models that describe them. For this reason, the conceptual models presented in this chapter reflect only our current understanding of ecosystem dynamics and as such are works in progress.

2.2.1 Conceptual Models and the Issue of Scale

Conceptual models should demonstrate the linkages between environmental stressors, ecosystem components, and expected consequences to that system (Figure 2.1; Thornton et al. 1993, Noon 2003). However, this approach is problematic because the boundaries between spatial, temporal, and ecological scale are indistinguishable in nature (O'Neill et al. 1986). Therefore all models are an artificial representation of reality as continuous phenomena are dissected into discrete categories.

A successful monitoring program must be based on a solid understanding of the cumulative processes responsible for driving change and the spatial and temporal scale at which this change is reflected

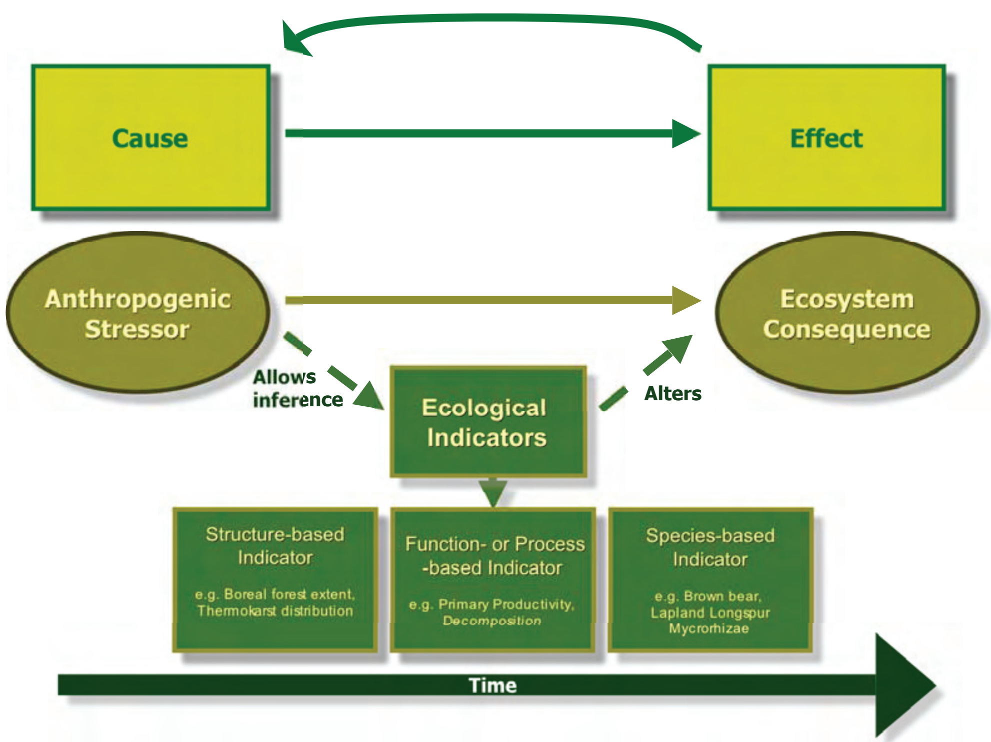


Figure 2.1. Simplified model showing the NPS approach to monitoring and the emphasis on indicators or vital signs, which should represent the cumulative effects of environmental degradation to ecosystems of interest. Redrawn and revised from Noon 2003.

in the ecosystem of interest. In addition, if the wrong ecosystem indicator or vital sign is selected or monitored at an inappropriate temporal or spatial scale, the inference from stressor to ecosystem consequence may be wrong (Figure 2.1).

2.2.2 Spatial Scale

Monitoring can usefully occur in situations as geographically limited as a single thaw pond, mountain slope, or heavily used fishing location. It is likely to be most useful if observations on this scale are incorporated into a broader perspective. In a sense, all larger scale monitoring plans are composed of local sampling schemes, with information obtained, collected, and interpreted to provide a broader picture. Not only does monitoring within the parks in our study area provide information on the condition of the park itself, but it may also be highly significant on a scale as large as the whole circumpolar north. Thus, while the primary function of long-term monitoring may be seen as providing useful information to be used in managing parks, or areas within parks, we should not lose sight of the potential for NPS-sponsored monitoring to affect our overall understanding of the northern environment. At the same time, it needs to be recognized that many of the changes that appear as local phenomena within the parks are, in fact, manifestations of much larger scale events that are expressed in a wide variety of ways over broad areas of the earth.

Although the ARCN Monitoring Program will focus on ecosystems found within the park boundaries, it is important to realize that changes to park ecosystems may be manifestations of larger scale phenomena (Figure 2.2). For this reason, collaboration amongst scientific peers working in other disciplines (e.g., anthropologists studying cultural dynamics or economic changes in local villages; earth

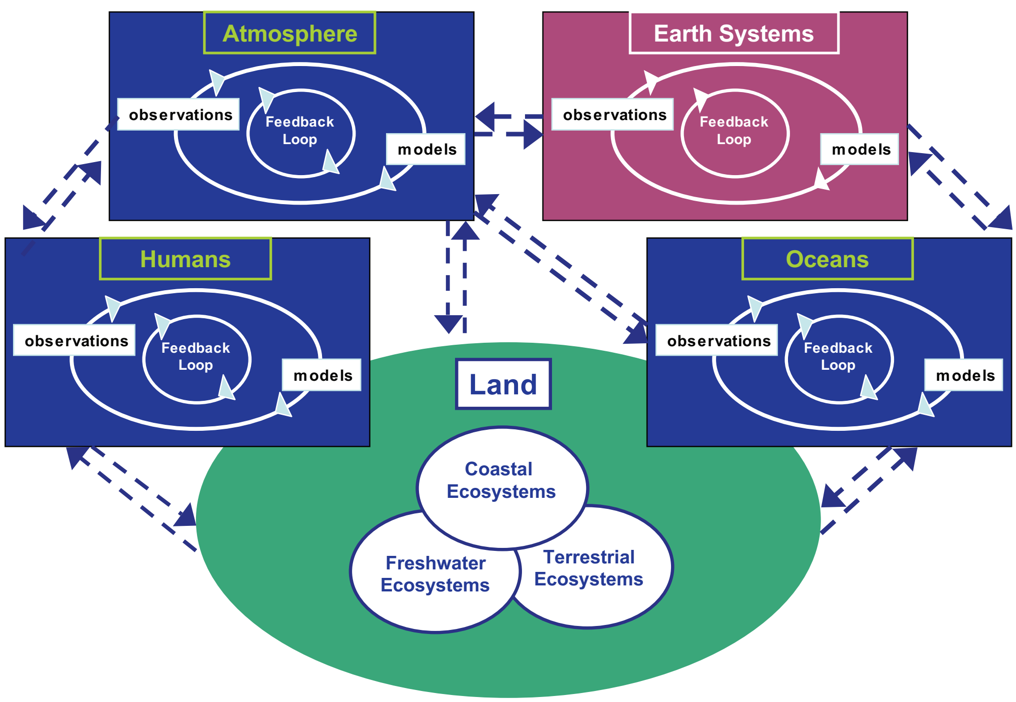


Figure 2.2. Although the ARCN Monitoring Program will focus on ecosystems found within the park boundaries (the "land" portion of this diagram) it is important to realize that changes to park ecosystems may be manifestations of larger scale phenonema occurring in the circumpolar north or world in general. For this reason, collaboration amongst scientific peers working in other disciplines will be crucial in laying the foundation for any long-term monitoring program in the Arctic. (Figure modified from Hinzman and Vörösmarty 2001).

system scientists studying the global water balance and its implications for Arctic Ocean circulation) will be crucial in laying the foundation for any long-term monitoring program in the Arctic. To this end, many circumpolar initiatives have or are being proposed for monitoring in the Arctic (see Chapter 1).

2.2.3 Finding an Appropriate Scale to Consider Anthropogenic Stressors in the Arctic

Human impacts to ARCN come at varying spatial scales. At the largest spatial scale, national and international politics, laws, and treaties could have an impact on arctic ecosystems (Figure 2.3). Although NPS may not have the resources or staff to directly affect legislation or treaty status, these global stressors must be considered when thinking about how arctic ecosystems might be changing. For example, it should be acknowledged that persistent organic pollutants (POPS), which are accumulating in the Arctic, their final repository, are coming from other parts of the world. The presence of these pollutants could be having an effect on the fecundity, reproduction, and survivorship of large mammal species living in arctic ecosystems (Arctic Monitoring and Assessment Programme 1997, Jepson et al. 1999, Wiig et al. 1998). A large suite of human activities in the circumpolar Arctic may also have a direct impact on ARCN ecosystems (Figure 2.4). For example, circumpolar feedbacks caused by human-induced climate change and its effect on arctic sea thickness and extent could have an impact on weather and climate in arctic ecosystems. This, in turn, could have an impact on the coastal ecosystems of ARCN and local subsistence practices (Figure 2.5). Local anthropogenic stressors within or adjacent to ARCN park boundaries could also have a direct impact on ARCN ecosystems (Figure 2.6). For example, the cumulative effects of oil and gas development on the North Slope could directly impact ARCN ecosystems in a variety of ways (National Research Council 2003). Possible ecosystem responses of anthropogenic impacts include things like changes in disturbance regime (increased fire),

Figure 2.3. Global natural drivers and anthropogenic stressors to ARCN ecosystems

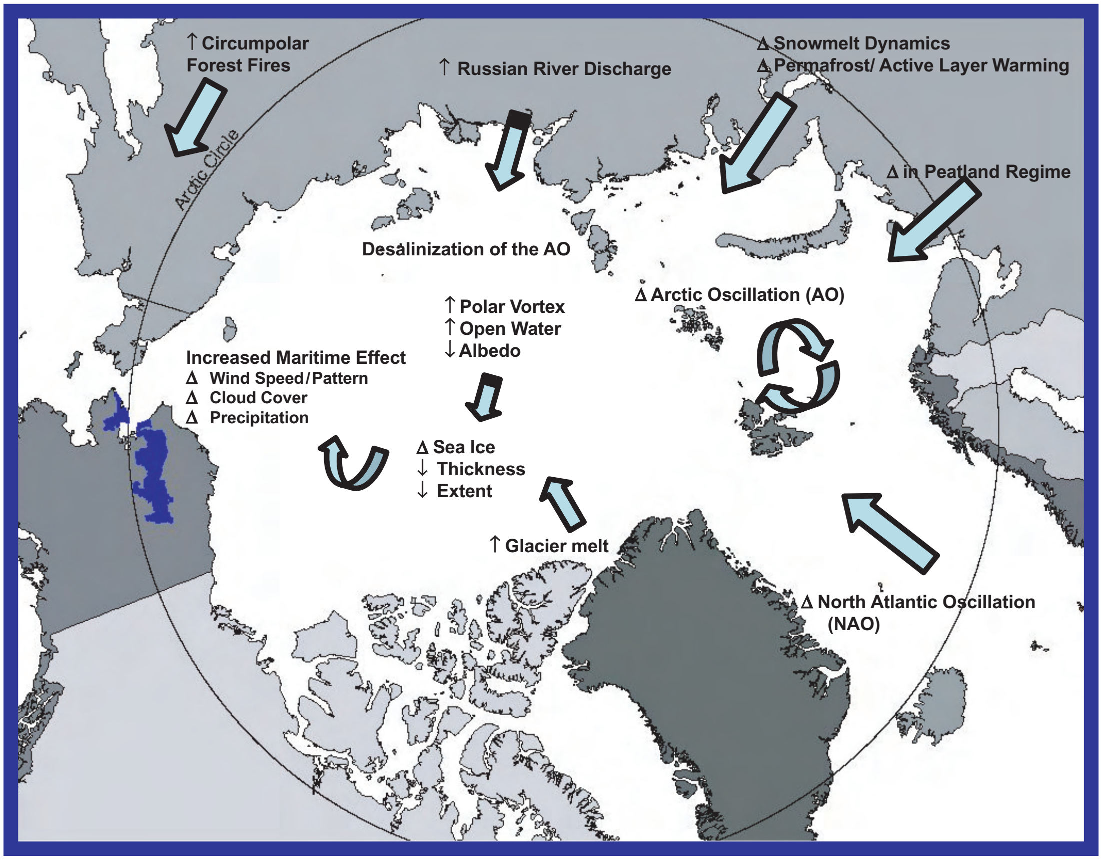


Figure 2.4. Circumpolar natural drivers and anthropogenic stressors to ARCN ecosystems

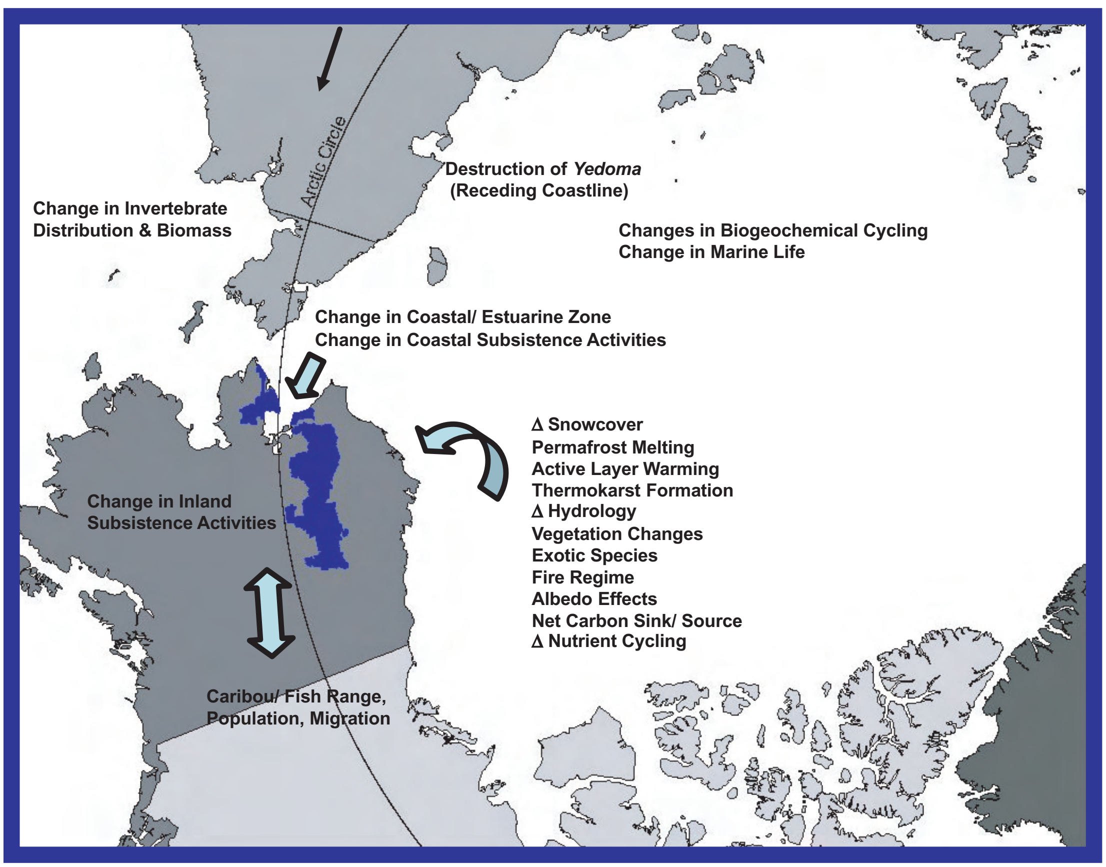


Figure 2.5. Regional natural drivers and anthropogenic stressors to ARCN ecosystems

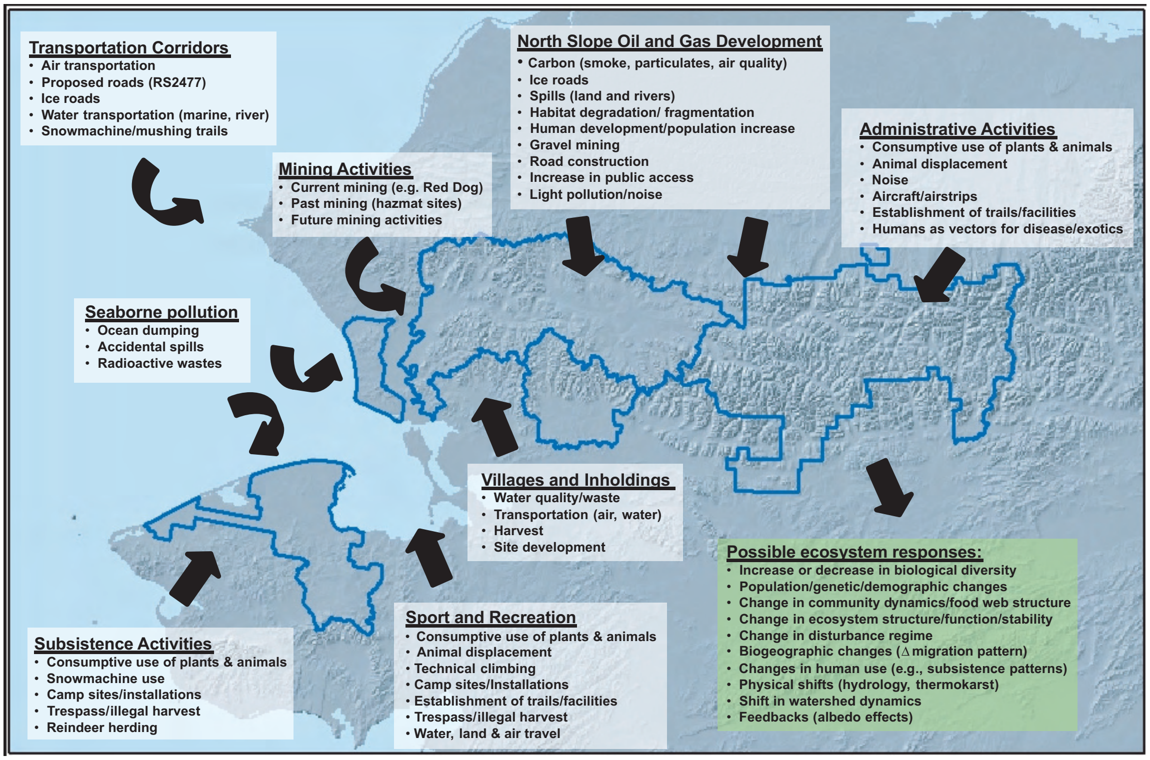


Figure 2.6. Regional natural drivers and anthropogenic stressors to ARCN ecosystems (within or adjacent to park boundaries)

physical shifts in the landscape (e.g., thermokarst formation), decreases in ecosystem stability and resilience (decrease in biodiversity), or population shifts of certain species (e.g., invasive species).

2.2.4 Time Scale and Monitoring in ARCN

Northern and western Alaska, perhaps even more than most regions of the world, have undergone enormous changes in the relatively recent geological past. In order to understand both the current array of organisms and the processes that maintain their interactions with the environment, it is necessary to approach them with a historical perspective in mind (Figure 2.7). In particular, we must recognize that the current environmental situation results from the interaction of processes that take place over greatly varying time scales. For purposes of discussion, we suggest the following time scales:

Long-term geological: dealing with events that have occurred over millions of years, such as mountain building, the distribution of certain substrates, etc.

Late Quaternary: changes that have been important in the late Pleistocene and Holocene, especially the roughly 20,000 years since the last glacial maximum. These would include the termination of continental glaciation over much of the Northern Hemisphere, the submergence of huge areas of continental shelf (especially the Bering Land Bridge), the extinction of many important megafaunal species, and the earliest activities of humans within our area.

Early-mid Holocene: changes primarily in vegetation and fauna associated with the emergence of modern ecosystems. Beginning of establishment of modern coastal features, such as the beach ridges of Cape Krusenstern and Cape Espenberg. Stabilization of many terrestrial features such as dunes and loess deposits.

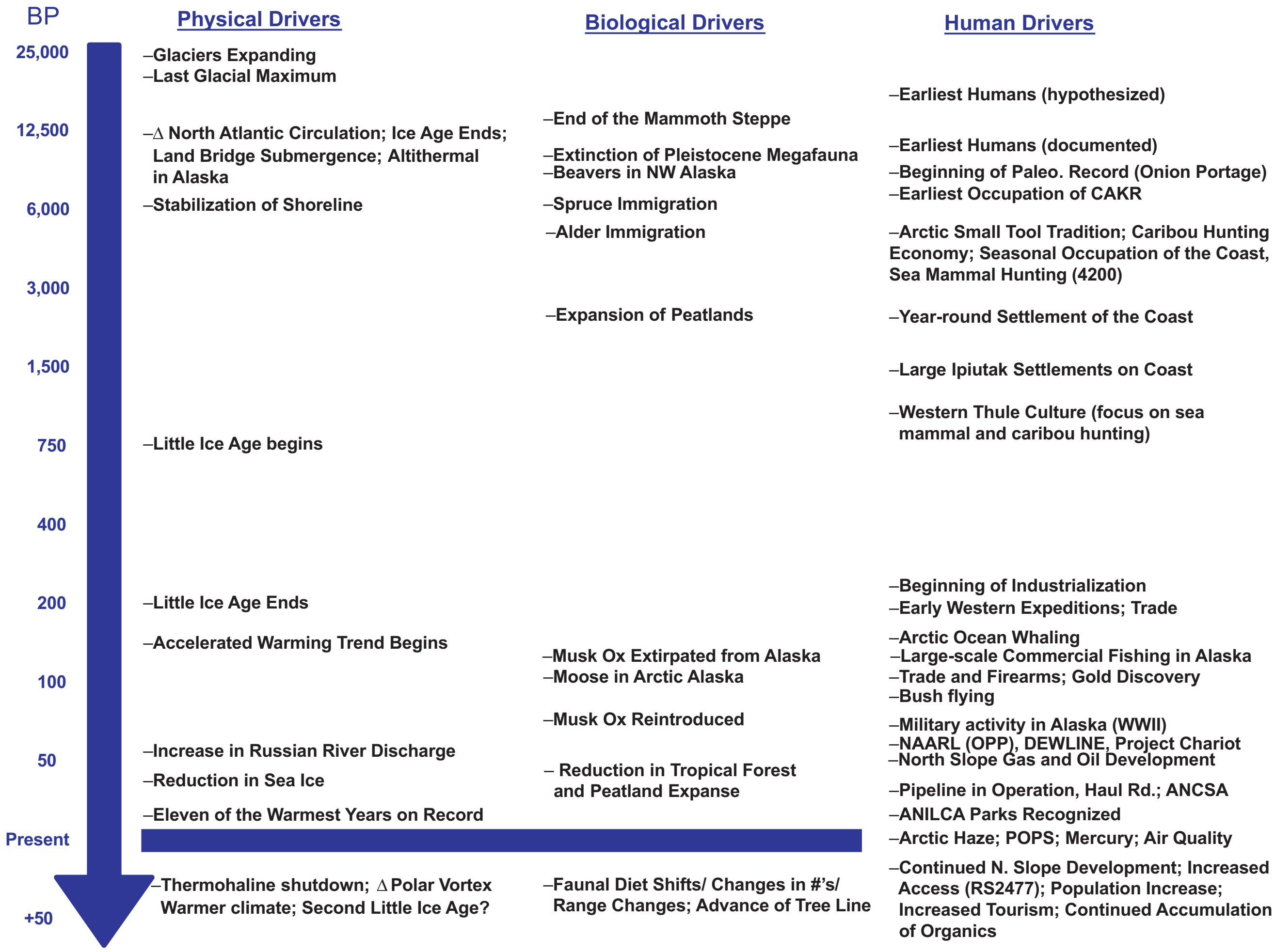


Figure 2.7. Significant physical, biological, and human drivers in the Arctic in the last 25,000 years before present

Prehistoric: the emergence of the ancestors of the indigenous cultures of the area and the increasing importance of archaeological sites and materials as sources of data on the nature of the environment.

Historic–current: the time including the influence of Western industrial society on the environments and peoples of our area, beginning soon after 1,800 C.E.

Short term: many of the phenomena with which we are concerned may be evident in the course of a very few years. They may be individual, recurrent, or cyclical.

2.3 Terrestrial Ecosystems of the Arctic Network

It is convenient, although not altogether precise, to divide the terrestrial ecosystems of ARCN into upland and lowland elements. Upland environments are characterized by extensive areas of exposed bedrock, shallow, unstable soils, steep slopes, and small, high-energy streams. Lowland areas have little relief, gentle slopes, often deep alluvial deposits, and, in our area, usually heavily permafrost and ice-rich soils and substrates. They often contain, or are associated with, large, slow-moving watercourses with extensive sandbars and other alluvial deposits. Upland (montane or alpine) situations may occur at almost any elevation within ARCN, since the traditional lower boundary for alpine regions, the treeline, is never more than 500 to 700 m above sea level. Much of ARCN lies beyond the arctic (latitudinal) treeline, so that even the lowlands are tundra covered and have many of the aspects of alpine situations in more temperate regions. The distinguishing features between uplands and lowlands, then, depend on the amount of relief and whether erosional or depositional processes dominate the landscape. It is possible to cross from upland to lowland environments within a few meters and with little or no elevation change, so much of ARCN is a complex mosaic of the two.

Figures 2.8 and 2.9 provide models of the array of landscapes and ecosystems generally associated with uplands and lowlands. They also show graphically the complex interrelationship between the two elements.

2.4 Mountain and Upland Ecosystems of ARCN

Upland ecosystems in ARCN are areas that contain higher elevations and moderate to high relief along with narrower and more sinuous river valleys (Figure 2.8).

Underlying geology is a key feature of the landscape to consider when thinking about ecosystem drivers within the arctic parks. The nature of the bedrock can affect or control the nature of the ecosystems in several ways. Exposed, resistant bedrock is often characterized by steep slopes and minimal soil development. Certain kinds of rock are often associated with particular geomorphic features. For example, granitic outcrops are often the basis for spectacular alpine features found in the Arrigetch Peaks and Mt. Igikpak regions in GAAR. In other areas, especially BELA, granite exposures are responsible for the formation of clusters of tors. Lava flows of comparatively recent age, such as are found widely in BELA, form extensive rocky barrens and are often associated with features such as Marr Lakes. The chemical nature of the underlying bedrock may also have a profound effect on the vegetation. This is particularly evident in the case of the extensive areas of limestone and other carbonate rocks, such as those found in CAKR and locally in the other parks.

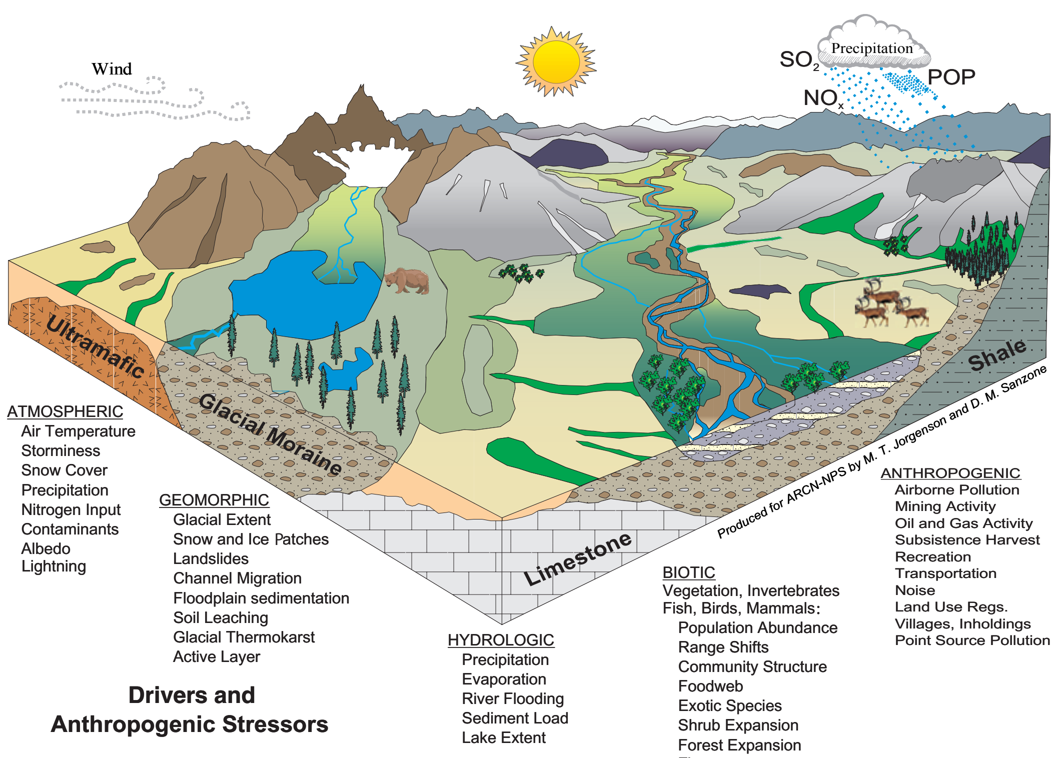


Figure 2.8. Mountain and upland ecosystems of ARCN and natural drivers and anthropogenic stressors

The steep slopes and high elevations characteristic of mountainous terrain provide the basis for many characteristic geomorphic features. Prominent among these are features associated with past and present glaciation. At various times during the earlier Pleistocene, a considerable portion of ARCN was covered by large ice sheets. However, during the latest glacial maximum, about 20,000 years ago, large glaciers were much more localized and occurred mainly in the central Brooks Range. Local glaciers did, however, expand far beyond their present limits in the western Brooks Range and the Seward Peninsula. Currently, glaciers are limited in extent and occur mainly in GAAR.

Aside from the tectonic processes that created the mountains, glacial action is the most significant geomorphic process in virtually all the montane areas in the cool temperate and polar regions. In ARCN, the major features of the landscape of GAAR are of glacial origin.

The more conspicuous geomorphic features of glaciated mountain regions are erosional: cirques, horns, and glacial valleys, for example. Glaciation also provides an array of depositional features, such as moraines and valley trains. Many of the features lying well beyond the mountain ranges, such as the rolling terrain of the middle Noatak Valley, are glacial deposits. Glacial action has also been the prime source of sediments for many of the stream deposits throughout much of ARCN. The shrinkage or disappearance of glaciers can remove the main source of sediments from streams and rivers.

Glaciers are uniquely sensitive to changing climate; they are important sources of data in climatic studies. While glaciers normally retreat during warming periods, warmer climates may, paradoxically, cause glaciers to expand because of increased snowfall. The presence of glaciers can have profound effects on stream hydrology, since maximum stream flow from glaciers occurs during warm, sunny periods of maximum melt, rather than times of high precipitation.

In addition to true glaciers, there are extensive areas of late-lying or perennial snow and ice in the mountainous regions of ARCN. These affect the environment in a number of ways: they provide moisture sources during dry periods in summer, and they often shorten the growing season to the extent they inhibit the presence of many forms of vegetation. Snowbeds and overflow ice (aufeis) fields are perhaps even more sensitive to climate change than are glaciers.

Periglacial phenomena are characteristic of unglaciated portions of cold regions; they include permafrost and a wide variety of features associated with intense freeze-thaw cycles. Some of the most complex phenomena associated with permafrost occur in deep, unconsolidated sediments on lowlands; they are treated in the next section. In montane environments, important periglacial phenomena involve frost wedging and cracking of bedrock and outcrops and boulders and various forms of mass wasting. Retreating glaciers leave oversteepened slopes on the sides and headwalls of empty cirques and valleys. Frost wedging of the steep walls results in deep and unstable deposits of debris at the bottom of cliffs and crags, and these are subject to landslides. Solifluction often occurs on vegetated slopes. This is the process by which soil creeps downslope in summer, when the top layer is unfrozen and saturated with meltwater.

In the mountainous regions of ARCN, vegetation communities range from the polar desert of the high, barren summits through various forms of alpine tundra, extensive brushlands, to, in the more inland areas, the upper reaches of boreal forest formed mainly of white spruce (*Picea glauca*). Polar desert communities in ARCN are similar in composition to that found in high arctic regions such as the northern Canadian Arctic Archipelago. Vascular plants are almost entirely herbaceous and mainly circumpolar species. Moss patches are extensively developed in moist areas. Much of the bare rock faces are heavily vegetated with lichens. Areas that are snow free for only a few weeks in late summer are sparsely vegetated.

Alpine tundra is a broad category; it includes a great variety of local forms of vegetation dominated by herbaceous plants and low shrubs. Some of the variation is associated with altitude, some with slope steepness and exposure, some with soil and substrate structure and chemistry, and some with moisture availability. The number of potential species available is high, and many of the rarer species of plants from our area are found in alpine tundra locations, where they may be locally abundant but widely separated from other colonies. Alpine tundra provides important foraging areas for large herbivores such as Dall's sheep (at higher elevations), caribou, and, where they occur, muskox. Some smaller herbivores, such as marmots, are largely confined to alpine tundra. Changes over time in alpine tundra tend to be subtle, and the relevance of the changes to broader scale events is usually difficult to understand. Some of the greatest diversity in alpine tundra species composition occurs in seepage areas, and these are usually related to late-lying snow beds, so changes in snow cover regime may be well correlated with changes in distribution and composition of certain alpine tundra communities. Alpine tundra generally becomes richer in shrubs at lower elevations and merges with shrubland. Alternatively, it may grade more or less imperceptibly into the tussock tundra and wet meadows characteristic of lowland tundra.

Shrubland is characteristic of the lower slopes of mountains throughout ARCN, but is especially well developed immediately above (or beyond) treeline in the Brooks Range. The species composition of shrubland varies widely but is often correlated with the direction of slope exposure. Cooler, moister slopes are generally dominated by dense alder (*Alnus crispa*) thickets. These may occur in other situations as well, especially on glacial moraines and outwash plains. Several species of willow (*Salix* spp.) occur widely in shrubland, and the exact species compositions seems to depend on a variety of factors such as elevation, moisture availability, soil type, and slope stability.

Boreal forest is a minor component of the upland vegetation. Spruce stands are found along the lower reaches of some of the watercourses. Isolated individual trees are found in the lower reaches of brushland, where trees may be advancing. There has been a great deal of study of the advance and retreat of treeline over time in various parts of the north, and these studies provide important evidence for long-term climatic trends. In addition to spruce forest, there are often small stands of cottonwood (*Populus balsamifera* and *P. deltoides*) occurring well beyond or above the conifer treeline. In some areas there are also small riparian poplar woodlands. These may host outlying populations of species of insects and nesting birds that are otherwise typical of the boreal forest.

2.4.1 Arctic Lowland Ecosystems

Lowlands are generally areas of low relief and low elevation (Figure 2.9). Within ARCN we define them on the basis that their substrate is mainly the result of depositional factors. With the exception of recent lava flows within BELA, there is little exposed bedrock. As mentioned above, exposed bedrock in the form of isolated crags and tors creates a montane environment, even when they occur at low elevations.

The geomorphic features of lowland areas are generally the result of direct glacial deposition (moraine), alluvial deposits associated with streams, mass wasting downslope, and Aeolian deposits, most of which are now stabilized. Thus, most lowland ecosystems are developed on landscapes that feature deep deposits of unconsolidated material. Since the mean annual temperatures throughout ARCN are well below freezing, water contained in this material is usually frozen; most of ARCN lies within the zone of continuous permafrost. Although permafrost is defined as perennially frozen material, permafrosted landscapes developed on unconsolidated deposits are often quite dynamic. In addition to the active layer—the seasonally thawed soil above the permafrost—there are a number of situations

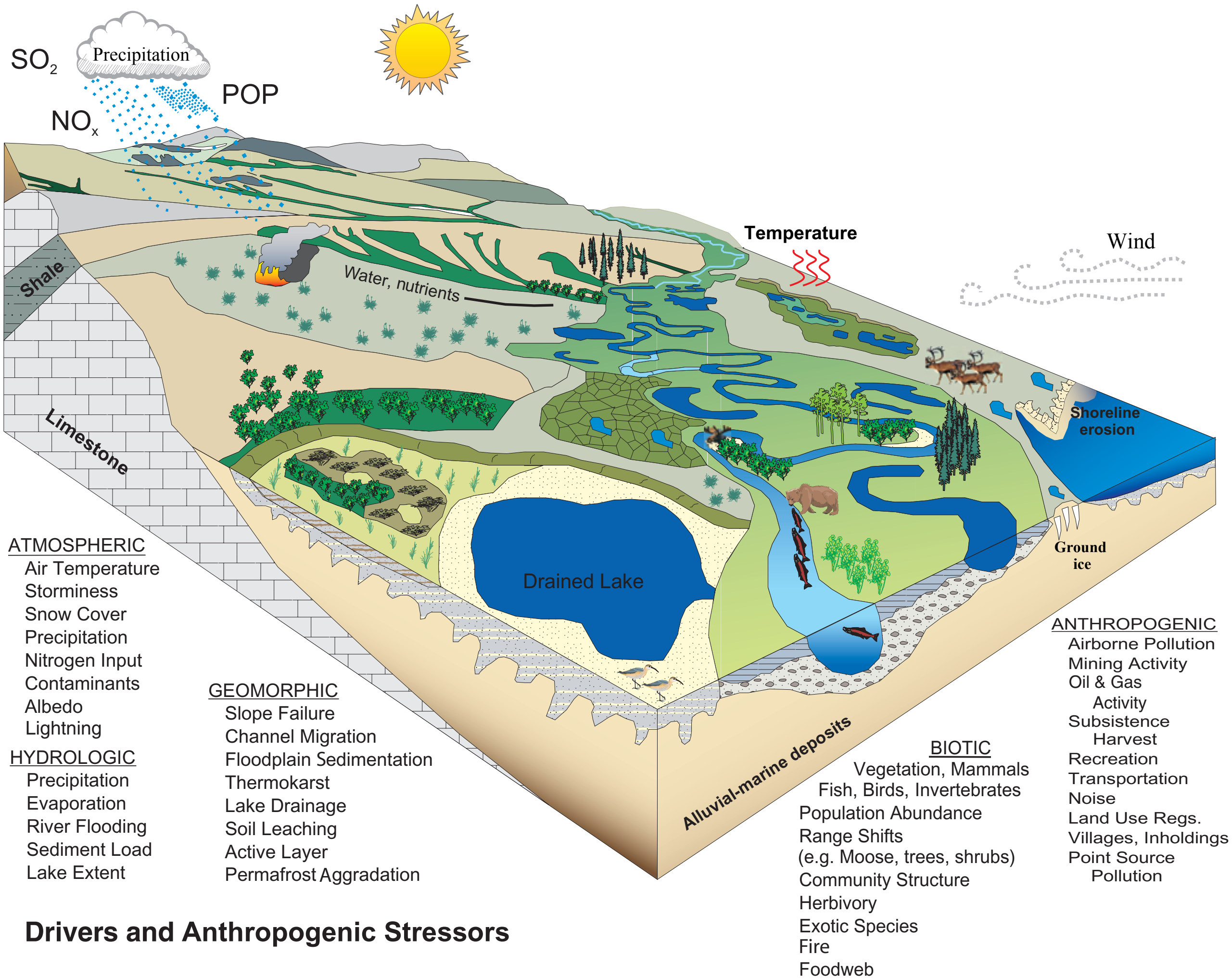


Figure 2.9. Arctic lowland ecosystems of ARCN

in which freezing and thawing processes create major alterations and instabilities in permafrosted terrain. These include ice-wedge polygon formation and other types of processes that form patterned ground. Of particular interest are thermokarst processes. These are the result of the thawing of ice-rich frozen ground; they often result in soil slumps, the creation of ponds and migration of drainage channels, and the draining of older thaw lakes. Thermokarst processes are known to be increasingly active in many polar regions in recent decades.

Permafrost action is less conspicuous in active stream systems and in Aeolian features. In these situations drainage is better, the active layer is deeper, and redeposition of materials by stream action tends to mask the more slowly acting permafrost processes. Sand and gravel bars cover large areas of the lowlands, as even small streams often carry heavy sediment loads during some seasons of the year. Aeolian features are currently mostly stable and covered with vegetation; the most conspicuous exceptions are the dune areas in the Kobuk Valley.

Climate, terrain, and vegetation strongly influence the occurrence, extent and severity of fires within the lowland ecosystems of the Arctic Network. The subarctic boreal forests and low arctic tundra biomes are subject to periodic fires. The frequency and extent of the fires is governed by vegetative, geographic, and climatic factors. One of the major uncertainties regarding the effects of climate change on terrestrial ecosystems in the Arctic is how warming will affect the extent and frequency of tundra and subarctic boreal forest wildfires and what effects such fire disturbance would have on these ecosystems. Tundra and taiga fires generally accelerate carbon loss due to both direct burning and subsequent warming of soils causing higher rates of decomposition.

Boreal forest covers broad areas of KOVA and GAAR, some parts of NOAT, and almost none of BELA and CAKR. The main component of the boreal forest is spruce (*Picea* spp.), and the distribution of this species is closely associated with temperatures during the growing season. The migration of spruce forest into the surrounding tundra areas is the subject of several current studies; the results generally indicate that this is occurring, although not in a uniform or entirely predictable fashion. The presence or absence of spruce forest is important for several reasons. Many vertebrate species are more or less dependent on spruce; these include red squirrels, spruce grouse, hare species, and Canadian lynx. Many invertebrates such as bark beetles are both dependent on spruce and can cause major mortality of the spruce forest, as has happened recently in southcentral Alaska. Spruce forest also affects the landscape in that it changes the albedo and reduces soil temperature by shading the ground surface and modifying snow accumulation.

Various kinds of brushland are widespread in the lowlands of ARCN. Many of these are willow thickets associated with streams and comprised of many species, often depending on such factors as stream size and bank stability. Other types of scrub vegetation involving willow species and dwarf birch (*Betula nana* and *B. glandulosa*) are widespread. Alder (*Alnus crispa*) stands are more common on slopes and moist valley sides, usually in the foothills of the mountains.

The most widespread type of vegetation in most lowland situations is sedge meadow. This is the main component of low arctic tundra in the region, and it generally consists of two types: wet meadows and tussock tundra. Tussock tundra covers enormous areas of rolling terrain, such as occurs throughout the middle Noatak drainage. Its dominant species is a cottongrass (*Eriophorum vaginatum*) which forms dense, peaty tussocks, each surrounded by a moist, shaded moat. These areas provide important habitat for caribou during much of the year. They are also populated by a wide array of small mammals, mainly microtine rodents and shrews.

Wet meadows are usually associated with flat, heavily permafrosted terrain. The vegetation consists largely of sedges and grasses. Water stands on these meadows during much of the year, and they form a transition between aquatic and terrestrial environments. Wet meadows are often the areas most profoundly affected by changes in the permafrost regime. These include natural cycles that tend to create and drain lakes and ponds, as well as anthropogenic changes. Many of the lowland areas have been extensively investigated for potential petroleum development; others have served as corridors for moving heavy equipment to mineral exploration sites. These activities often affect the tundra surface to such an extent that they cause changes in the permafrost regime, resulting in extensive anthropogenic thermokarst. Roads from established mines, such as the Red Dog mine near CAKR, cross lowland areas. Heavy vehicle traffic affects not only the roadbed itself but the surrounding environment from dust, exhaust products, and the deposition of heavy metal residues.

Most of the villages within ARCN are located in lowland areas, especially near rivers, so many subsistence activities take place in the surrounding lowlands. Caribou and moose spend much of the year in lowland areas, and they are usually extensively hunted, as are waterfowl and some small game. The lowlands near villages are often subject to heavy traffic from snowmobiles and ATVs.

2.5 Freshwater Ecosystems of ARCN

2.5.1 The Circumpolar Hydrologic Cycle and its Implications for ARCN

The hydrologic cycle figures prominently into the dynamics of arctic ecosystems (Figure 2.10). In the Arctic, this tightly coupled system links land, ocean, and atmospheric components together. The contrast between summer and winter water cycles over the arctic land mass is extreme. During the summer months, the flux of mass, energy, and nutrients downstream is concentrated in a single sharp peak flow event that brings moisture to terrestrial arctic ecosystems, eventually ending up in the ocean. Surface flow, ponding, and cycles of free-thaw are the primary drivers of erosion and geomorphic change (Vörösmarty et al. 2001). In winter, ice and snow radically transform the land surface, increasing surface albedo and reducing the amount of solar energy absorbed. A unique feature of the arctic hydrologic cycle is the presence of permafrost and its associated active layer. Permafrost limits the amount of subsurface water storage, which in turn is largely controlled by surface heat flux. Although ARCN will focus its monitoring effort on the land component (Figure 2.2) of this tightly coupled land-ocean-atmosphere system, it is necessary to point out that the surface water and energy balance is ultimately linked to the pan arctic water cycle and all of its various feedbacks.

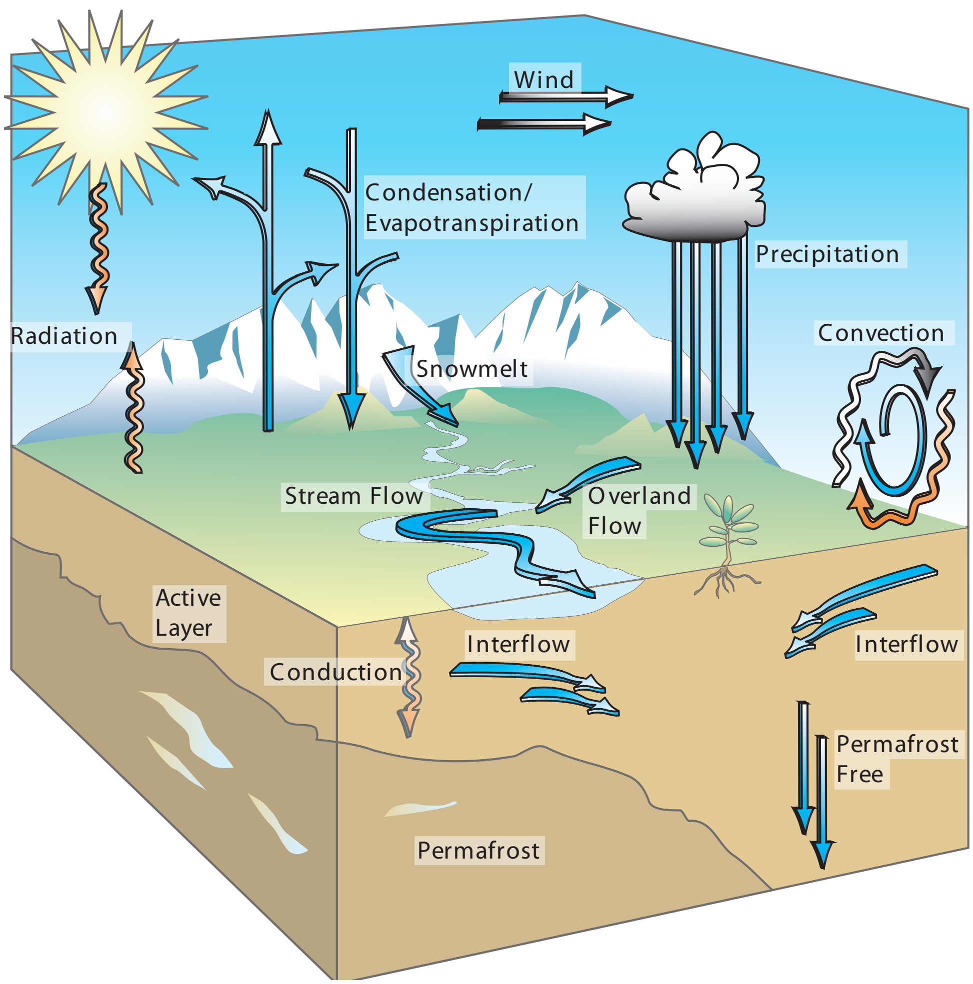


Figure 2.10. Conceptual model of the land surface component of the arctic hydrologic cycle and related water cycle dynamics. From the Arctic Community-wide Hydrologic Analysis and Monitoring Program (Arctic-CHAMP) Strategy Model (Vörösmarty et al. 2001).

2.5.2 Large Rivers of the Arctic Network

ARCN contains many large river systems, including the Noatak and Kobuk rivers that drain west into the Kotzebue Sound and Chukchi Sea. Large rivers in ARCN usually meander through broad valleys and contain numerous side channels and sloughs (Figures 2.8 and 2.9). The structure of these large river floodplains allows for the lateral transfer of nutrients and energy throughout the valley bottom. Although few studies have been conducted on the surface-subsurface dynamics of these large arctic river systems, this exchange between surface and hyporheic waters may nonetheless be important to the functioning of these systems.

Many of the tributaries to these large rivers originate in the Brooks Range as clear-water or silt-rich glacier-fed streams. These large river systems serve as conduits for carbon, nutrient, and trace metal transport connecting the surrounding watershed with areas further downstream. In addition, many anadromous fish, riparian birds, and large mammals use these large river corridors for migration or foraging, providing yet another opportunity for exchange of energy and nutrients up or downstream (Oswood 1997).

Historically, much of the gravel used for construction of roads and pads in arctic Alaska has been obtained from deposits within the floodplains of large rivers. Gravel mining in floodplains of large rivers has been shown to substantially alter flow regimes of large river systems (Joyce 1980). The Alaska Department of Natural Resources (DNR) identified 2,477 potential RS 2477 rights-of-way in the state of Alaska and found 647 that qualify. In 1998 the state legislature passed a law declaring 600 routes as RS 2477 rights-of-way by public use. In 13 national parklands in Alaska, the State of Alaska has claimed 112 potential roads totaling 2,272 miles. To date, 21 possible RS2477 rights-of-way have been identified by the State of Alaska in the ARCN parks (NPS, personal communication). Road development in ARCN parks could have a detrimental impact to many of the large river systems because the construction and use of gravel roads could interrupt or alter stream flow.

2.5.3 Headwater Streams of the Arctic Network

Three main types of headwater streams have been identified in the Alaskan Arctic: mountain, tundra, and spring streams (Craig and McCart 1975).

In ARCN there are two types of mountain streams: glacier-fed mountain streams that originate as cirque glaciers high in the Brooks Range and streams fed mainly by precipitation and snowmelt. Mountain streams in ARCN drain north, south, and west out of the Brooks Range. Tundra streams are found in the foothills and coastal plain areas of ARCN, are fed mainly by snowmelt and precipitation, and are underlain by peat. Mountain and tundra streams experience extreme fluctuations in flow, with discharge highest in spring and early summer and little or no flow in winter when runoff ceases and most or all of the water column freezes. Mountain and tundra streams that experience extreme physical disturbances such as spring snowmelt and winter freezing are common in high-latitude climates. These streams tend to have low species diversity and secondary production because few aquatic species are adapted to tolerate such extreme physical changes in their environment (Figure 2.11).

Spring streams are fed by groundwater below or within the permafrost layer or by deep lakes and flow all year long. In many spring streams in the Arctic, water temperatures exceed 5°C all year long (Craig and McCart 1975). These perennial streams are distributed throughout ARCN, contain a larger number of aquatic species, and most likely serve as refugia for taxa that are not tolerant to freezing (Figure 2.12).

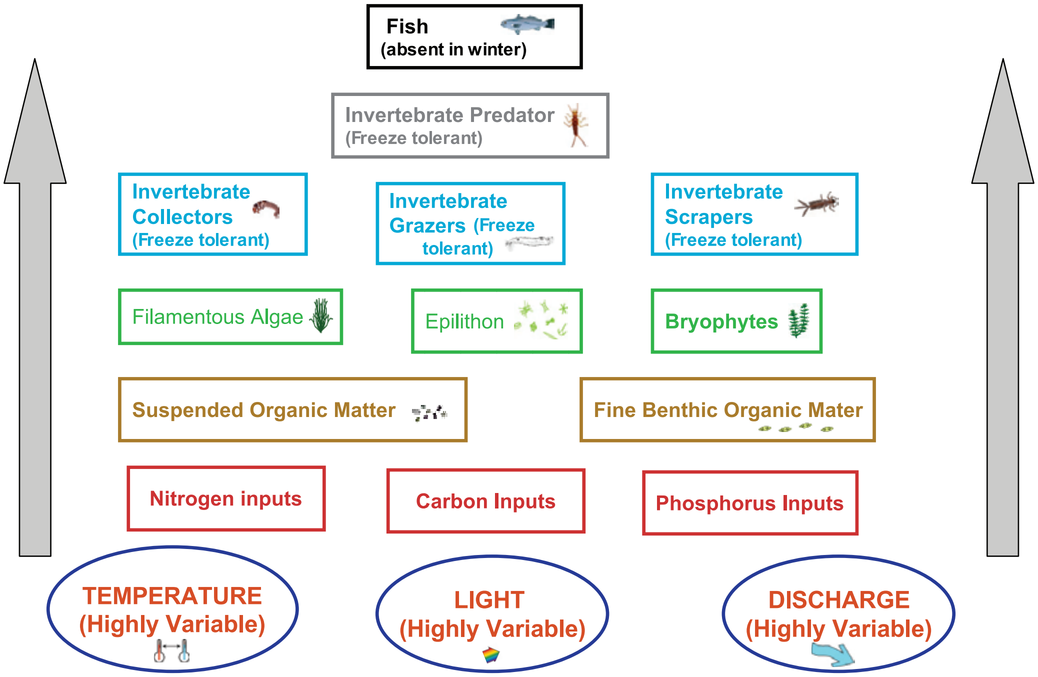


Figure 2.11. Simplified mountain or tundra stream food web. Physical disturbances and extreme fluctuations in temperature, light, and discharge exert control of these food webs. Circles indicate physical drivers, boxes represent standing stocks, and arrows represent general direction of energy flow.

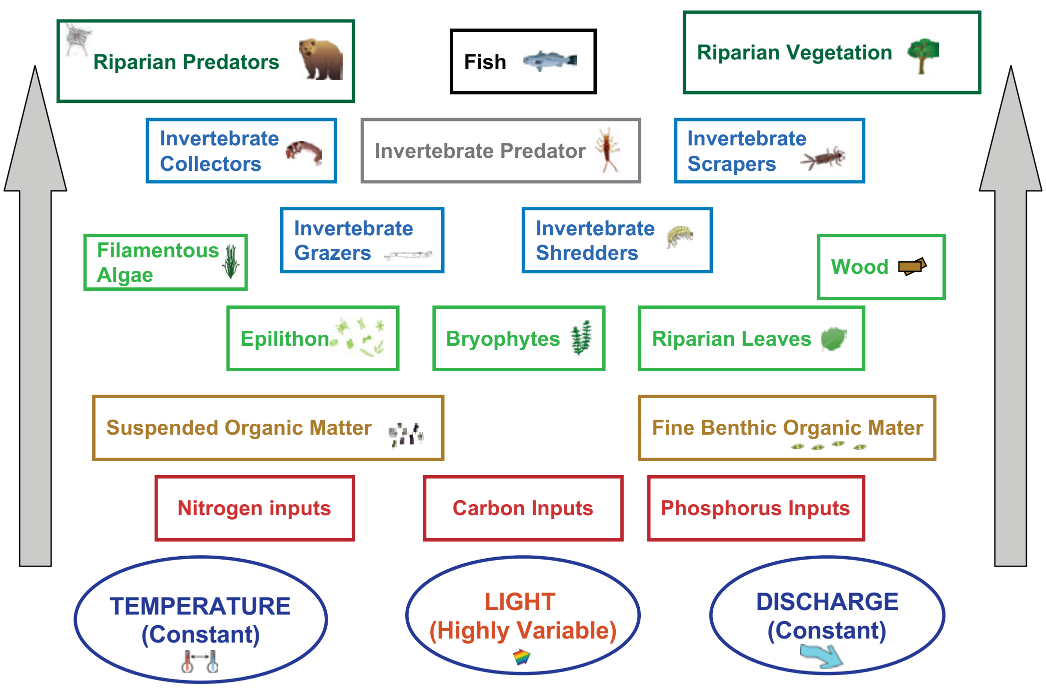


Figure 2.12. Simplified arctic spring-fed stream food web. Extreme physical disturbances are much less common in these streams than arctic mountain or tundra streams because water temperatures and discharge remain relatively constant throughout the year. However, communities in these streams do experience extreme variation in light regimes. Circles indicate physical drivers, boxes represent standing stocks, and arrows represent general direction of energy flow.

2.5.4 Lakes of the Arctic Network

There are many lakes of varying sizes in ARCN (Figures 2.8 and 2.9). Many of the large deep lakes such as Chandler, Selby, Feniak, and Matcharak are well known in this region; however, thousands of shallow lakes and wetlands are distributed throughout the parks. Water from large freshwater lakes is often used to build ice roads for winter travel and oil exploration in the Alaskan Arctic. "For lakes that do not support wintering fish, there is essentially no current regulation of winter water withdrawals, and the amount estimated to be present during summer is typically set as the withdrawal limit … [which] essentially allows withdrawal of all remaining unfrozen water in the lake at the time of withdrawal" (National Research Council 2003). Since little baseline data on the lakes of ARCN has been collected, it will be hard to monitor the actual impacts of water withdrawal on these ecosystems if additional road corridors are built within or abutting ARCN parklands.

2.6 Coastal Ecosystems of ARCN

Coastal ecosystems in ARCN are confined to CAKR, whose central feature is the extensive lagoon and barrier beach system that encompasses most of the southern portion of the monument, and BELA, much of whose northern boundary is the Chukchi Sea and Kotzebue Sound coast of the Seward Peninsula. ARCN does not include any offshore waters, but the boundary between marine and coastal ecosystems is less distinct biologically than it is geographically. Marine processes and events strongly affect the coastal environment, and vice versa. This is particularly true within ARCN, since the surrounding seas are shallow and the sea bed was emergent as recently as the terminal Pleistocene, roughly 10,000 years ago. Rising sea levels during the Holocene have been instrumental in shaping the landscape and ecosystems of the coastal regions of ARCN, and this continues in the present.

Polar marine ecosystems are coming to be recognized as being extraordinarily sensitive to environmental change. Reductions in sea ice cover can have profound effects on ice-dependent species such as polar bears and ringed seals. The long food chains of the seas encourage the biological concentration of various pollutants at the higher trophic levels. Heavy exploitation of marine resources, especially ground fish, seems to have the potential to disrupt long-established ecosystems to the point that they change their essential nature. These changes may be, for all practical purposes, permanent. Fundamental changes seem to be occurring in the nature of the Bering Sea, within a few hundred kilometers of ARCN. The marine environment immediately adjacent to ARCN is thus of great interest to monitoring programs within the study area.

Coastal ecosystems within ARCN can, somewhat arbitrarily, be divided into four categories, which we have shown graphically as Figures 2.13, 2.14, 2.15, and 2.17. Rocky coastlines (Figure 2.13) are relatively rare within ARCN. More extensive are shorelines where the sea borders low-lying tundra developed on unconsolidated sediments (Figure 2.14). Lagoon and barrier beach systems are extensive and important in both CAKR and BELA (Figure 2.15). Delta ecosystems are also an important habitat in coastal areas of ARCN (Figure 2.17).

2.6.1 Rocky Shores

Rocky shores occur mainly along the Kotzebue Sound coast of BELA. These shores are generally low-lying and are formed from lava flows of various ages (Figure 2.13). Above the inshore limit of storm beaches and beach deposits, the vegetation is often affected by salt carried onshore by wind; a few species of lichens and vascular plants are encouraged by or confined to saline situations. Near the eastern

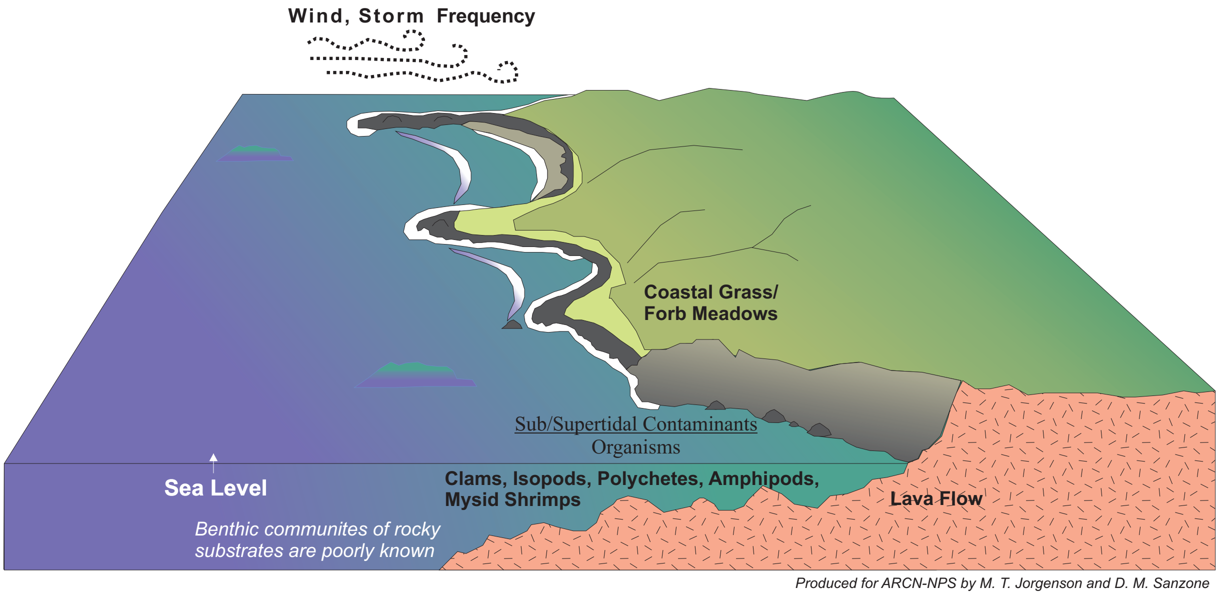


Figure 2.13. Rocky cliff shorelines of ARCN

boundary there are some sea cliffs that support small colonies of cliff-nesting seabirds. Except for seabirds, few if any species of vertebrates are characteristically found primarily along rocky shores. Benthic communities of rocky substrates are poorly known in this area and further study is needed.

2.6.2 Exposed Tundra Coastlines

In areas where lagoon and barrier beach systems have not developed, the coastal environment is often confined to a relatively narrow strip of beach (Figure 2.14). In some cases, the sea may even undercut deep deposits of ice-rich unconsolidated sediments, so that the interface between the sea and the terrestrial environment is a narrow zone of collapsing bluffs. In situations where the bluffs are low, no more than a meter or two high, sea ice may actually override the tundra during winter storms, leaving sea ice and detritus lying on the land surface.

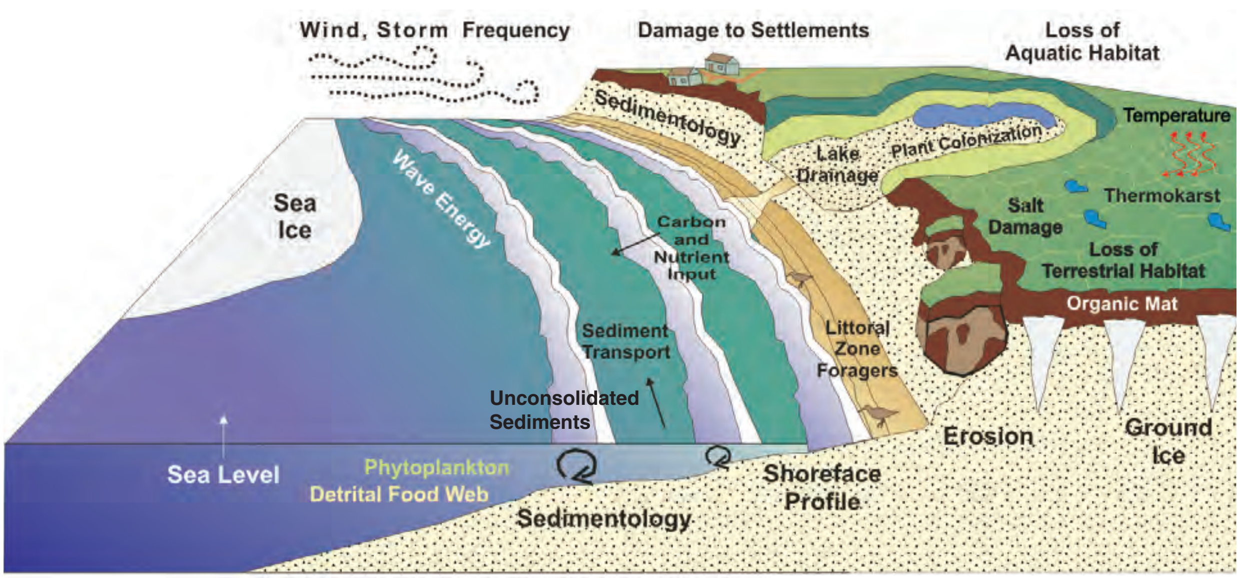


Figure 2.14. Exposed tundra coastline

Within ARCN, tundra coastlines are generally receding. The main phenomena associated with the incursion of the sea is the loss of terrestrial environment and the dispersal into the sea of sediments and nutrients that have been contained in the largely frozen terrestrial situations. The spread of saline conditions inland from salt spray and encroaching sea ice may also be important.

Another feature associated with encroaching seas is the drainage of coastal lakes and thaw ponds. Even shallow tundra ponds have generally existed for long periods of time—hundreds or thousands of years, and the presence of surface water that does not freeze to the bottom in winter allows the degradation of permafrost under the lake bed. When the encroaching seashore intersects the unfrozen and unconsolidated material of the lake bed and shore, a drainage channel may appear suddenly and the lake may drain entirely away over a short time. This provides a new, often well-drained and enriched soil surface for colonization by plants. Also, much of the surface sediment and nutrients of the lake bed may be discharged into the nearby marine ecosystem. Ultimately, a new permafrost regime will be initiated in the old lake bed, which is no longer insulated from the extreme cold of winter.

Since the actual area included in tundra coastlines is small and generally unstable, there are few vertebrate species specifically associated with this habitat type. It is often used by migrating waterfowl and shorebirds, and the often large quantity of detritus and carcasses of marine mammals and birds often attracts scavengers such as arctic foxes (*Alopex lagopus*) and ravens (*Corvus corax*).

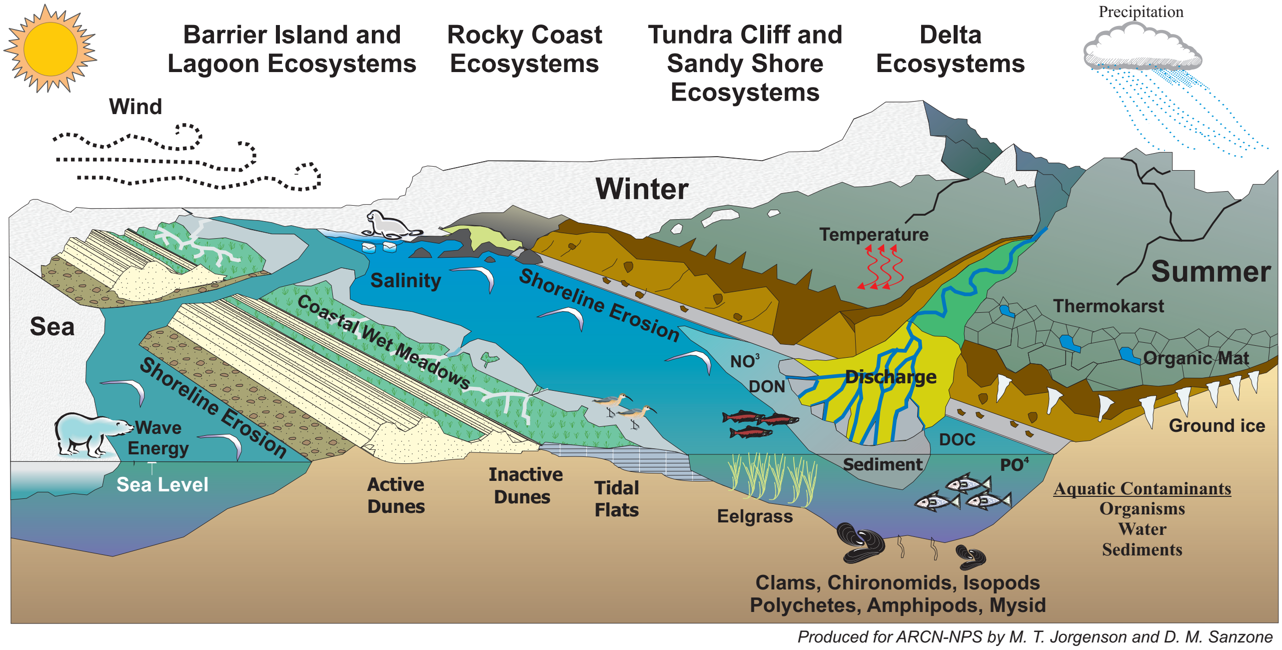
Tundra shorelines are subject to a good deal of anthropogenic disturbance, mainly because they are heavily used corridors for travel during the summer by ATVs. The narrowness of the beaches and the dry edges of the tundra bluffs confines vehicle travel to this narrow strip, and heavy erosion may result. Although there is also heavy winter travel by snowmobile, damage is less when the ground is frozen and snow-covered.

2.6.3 Lagoon and Barrier Beach Systems

Lagoon and barrier beach complexes (Figure 2.15) encompass most of the northern (Chukchi Sea) coast of BELA and are extensively developed along the coast of CAKR, especially in the southern portion. Cape Krusenstern itself is formed by an ancient and extensive barrier beach formation that is of enormous archaeological significance; this was central to the selection of CAKR as a national monument.

In contrast to tundra coastlines, barrier beaches are often aggrading, and many have been doing so for several thousand years, since the time when sea level reached nearly its present elevation. At Cape Krusenstern, over 150 separate beach ridges have been identified. The oldest to youngest are found in sequence from farthest inland to the presently active coast. This provides a time sequence similar to that more typically found in vertically stratified sites.

Barrier beach complexes may be as much as one kilometer or more wide; the ridges are separated by shallow backshore swales that parallel the ridges. The ridgetops generally support thin stands of vegetation, with lyme grass (*Elymus arenarius*) the dominant species. In areas of dunes, lyme grass stands are especially well developed. The swales are variable; some are water filled during much or all of the year, other are mostly dry. They provide a wide variety of habitats and are especially important as breeding grounds for shorebirds and terns. They may also support populations of various microtine rodents; these are preyed upon by foxes and predatory birds such as short-eared owls and northern harriers (*Circus cyaneus*). Some of the deeper, more stable hollows contain dense willow (*Salix* spp.) thickets.



Drivers and Anthropogenic Stressors

ATMOSPHERIC	OCEANOGRAPHIC	GEOMORPHIC	HYDROLOGIC	BIOTIC	ANTHROPOGENIC
↑ Air Temperature	↑ Sea Level	↑ Shoreline Erosion	Δ Precipitation	Vegetation, Invertebrates	↑ Airborne Pollution
↑ Storminess	↑ Storm surges	Δ Barrier Island Migration	Δ Evaporation	Fish, Birds, Mammals	Δ Mining Activity
↓ Snow Cover	↓ Sea Ice	Δ Marine Sedi. Transport	Δ River Discharge	Δ Population Abundance	Δ Oil and Gas Activity
Δ Precipitation	↑ Fetch Length	Δ Land Sediment Deposit.	Δ Lake Extent	Δ Range Shifts	Δ Subsistence Harvest
↑ Nitrogen Input	↑ Wave Energy	Δ Dune Formation/Scouring	Δ Nutrient Load	Δ Community Structure	Δ Recreation
↑ Contaminants		↑ Thermokarst	Δ Sediment Load	Δ Foodweb	Δ Transportation
↓ Albedo		↑ Active Layer		Δ Exotic Species	Δ Noise
					Δ Land Use Regs.
					Δ Villages, Inholdings
					Δ Pollution

Figure 2.15. Lagoon and barrier beach ecosystem

Although many barrier beaches have been stable for thousands of years, others are subject to very active shoreline erosion as well as aggradation. Wave action may actually breach the barriers, endangering coastal settlements and archaeological sites and radically changing the nature of associated lagoons.

Inland from the backshore may lie an extensive lagoon system. These lagoons are also highly variable, especially in terms of salinity. Some are actually open to the sea by way of passages through the barrier beach complex, and the waters are highly saline, modified only by the inflow of streams (Figure 2.16a). Other lagoons are generally only slightly brackish, their salinity derived from exceptional tides sending sea water up their discharge channels or, if the barrier beach is narrow, waves washing over it (Figure 2.16b). Lesser amounts of salt arrive from sea winds, and probably in some cases by percolation through the coarse sediments of the barrier beaches.

The shores and shallow portions of lagoons support extensive wet meadows; these are often punctuated by small ponds. This is an important habitat for many species of shorebirds and waterfowl. Certain species (e.g., red phalarope, *Phalaropus fulicaria*) are mostly confined as breeding species to coastal ponds. Waterfowl often congregate there in great numbers during molt and migration.

The inland shores of lagoons are also quite variable. In some cases they merge imperceptibly into adjacent wet coastal tundra. In others, they may border an eroding shoreline comparable to coastal tundra shorelines; these are usually less active, since there is less wave and tide action. Lagoons are also fed by streams originating inland; these may carry sediments and nutrients into the lagoon environment. The streams often form small estuaries, with extensive marshes and overflow channels.

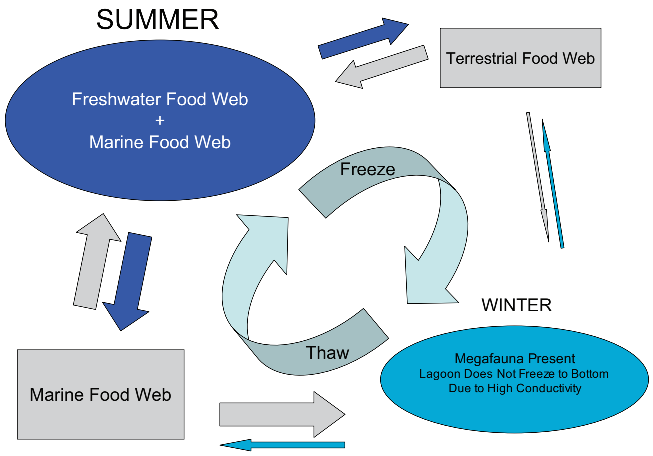


Figure 2.16a. Open lagoon systems of ARCN

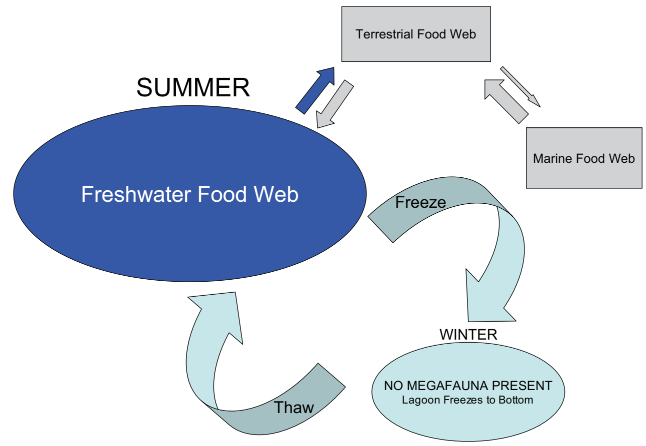


Figure 2.16b. Closed lagoon ecosystems of ARCN

Lagoons are relatively little used by large mammals. An exception is large, open lagoons, which may be important hauling areas for seals and may be visited by beluga whales. After winter freeze-up, coastal marshes may supply some fodder for herbivores. Caribou, moose, and muskox may visit barrier beaches at various times of the year. On-shore breezes may make them particularly attractive to caribou, because the wind keeps insects away.

Barrier beaches are subject to the same pressures from ATVs as tundra coastlines. The traveled corridors may be a bit wider and damage less obvious. During warmer seasons, when the ice is off the lagoons, they may receive some hunting and fishing pressure. Lagoons are obviously extremely sensitive to point source pollution from their shores or feeder streams, since they are largely closed systems.

2.6.4 Delta Ecosystems

The distinction between estuaries and lagoons is not always clear. Most streams that pass through lowland areas before entering the ocean are associated with complexes of beaches and other sediment deposits that form at least rudimentary lagoon systems. The features and processes that generally distinguish delta systems are significant river discharge and sediment load, strong effects of tidal influx, major rapid changes in water level and salinity, strong effects of ice from rivers and/or the sea, often extensive mud flats, and marshes with highly salt tolerant plant species (Figure 2.17). All of these vary greatly within the system, depending on factors such as microtopography and distance from the river shore and sea coast. Overall, estuarine systems are more dynamic, higher energy, and generally richer in nutrients and species of plants and animals than other coastal environments.

Estuaries are generally associated with sizeable streams, and these carry sediments from far inland. The higher energy streams may provide coarser sediments of sands and silts. Siltation may encourage mudflats in low-lying areas that might otherwise be heavily vegetated marshes. The high sediment load also may result in relatively high nutrient levels in the shallow waters and marshes. Association with larger streams also encourages the presence of anadromous fish. The estuaries and lower reaches of the feeder streams may provide important habitat for young salmonids.

As in the case of lagoons, estuaries are heavily frequented by birds, especially shorebirds and waterfowl. Estuarine shores are particularly well known as resting places for migrating shorebirds; their productivity and diversity provides a wide variety of invertebrates and small fish: high-energy food for birds that travel long distances.

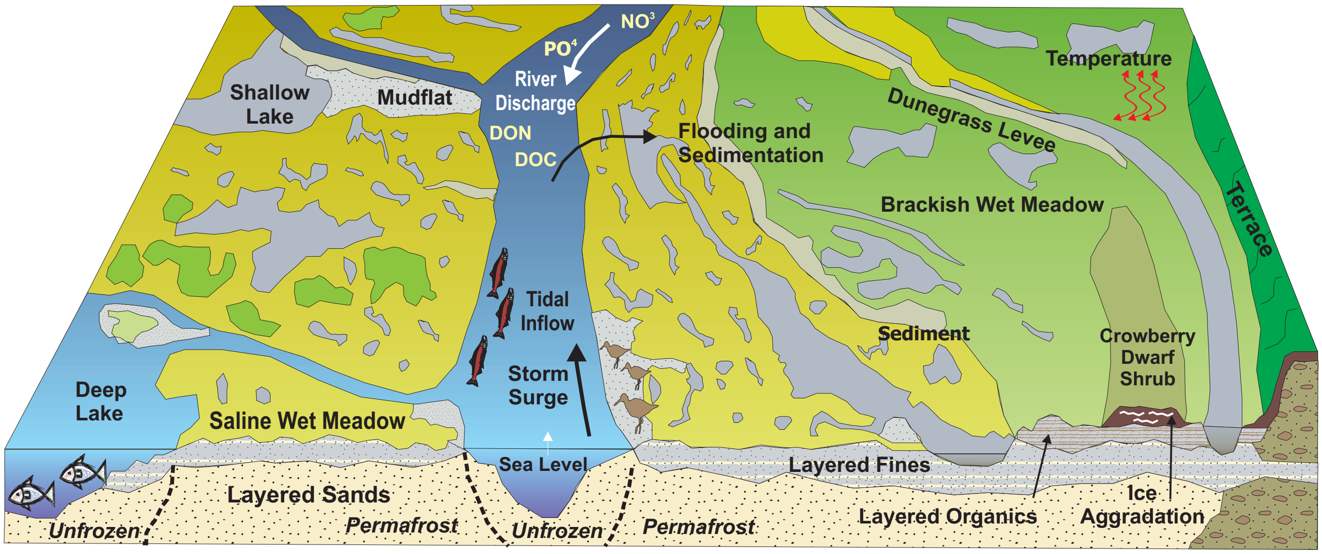


Figure 2.17. Delta ecosystems of ARCN

Estuarine ecosystems are often heavily used by subsistence hunters and both subsistence and commercial fishermen. Small runs of salmon, especially pink and chum salmon, occur in several of the river systems within coastal ARCN. Waterfowl are heavily used. Terrestrial vertebrates are generally uncommon in estuarine environments, especially in summer when footing is treacherous and insect swarms are heavy. Estuaries are affected by a variety of pollutants, both chemical and physical. Upstream activities may increase silt loads of streams, spills from boats and nearby hunting and fishing camps may be common, and some sea-borne organic pollutants may be locally significant. Because the most significant estuarine ecosystems occur within a meter or so above or below mean high tide level, estuarine ecosystems are strongly affected by minor changes in sea level.

2.7 Special Areas of Management Concern for ARCN

2.7.1 Conceptual Framework for Considering Climatic Change

It is generally accepted that global warming is occurring and that it is especially evident in high-latitude regions. While it is generally assumed that warming is a process that will continue into the foreseeable future, it is not inconceivable that cooling trends could develop. This is especially true over the very long (centuries or millennia) term, when orbital forcing or other factors could theoretically terminate the current interglacial. In the following model, we consider the potential effects of climatic cooling as well as warming. In the case of either warming or cooling trends in arctic environments, there are feedback mechanisms that suggest that some results of either process are counterintuitive. Scenarios based on regional warming or cooling trends that consider only annual means do not take into account changes in the seasonality that may occur. Increased seasonality, often associated with increased continentality, means, under a warming trend, warmer summers; decreased seasonality means warmer winters. Thus, a warming trend that involves increased winter temperature may increase precipitation, resulting in greater snowfall, delayed onset of the growing season, and quite possibly increased cloud cover during summer. A consequence of this could actually be lowered air and soil temperatures at ground level. The result of a warming trend might then appear at the vegetation level as stress on “warm climate” plants: those that require certain levels or duration of warmth during the growing season. Over the long term, this could, theoretically, result in the retraction or fragmentation of the ranges of “low arctic” species in areas such as the North Slope of the Brooks Range. This concept leads directly to concerns of range extension and retraction, such as the location of the treeline (see below).

The example developed above is obviously simplified and isolated from many related factors. It also says little about the scale of time and space over which effects might be visible. For example, a long-term warming trend would probably result in a thinning of the sea ice cover, so that open water near the north and west coast of Alaska would extend farther from the shore and remain open for more months of the year. This might set up a feedback loop in which additional warming was encouraged by the lowered albedo of the open sea as opposed to pack ice. On the other hand, increased open water could increase precipitation and cloudiness over the land, tending to reverse the warming trend. But this in turn would depend at least partially on wind and other weather patterns; these are notoriously difficult to predict, and there is usually wide variation between results when only slight modifications are made in the parameters that are fed into climatic models.

2.7.2 A Conceptual Framework for Considering Changing Plant Distribution Patterns in the Arctic Network: Northward Movement of Treeline

Long-term changes in climate are associated with changes in the distributions of various organisms (Figure 2.18). In the North, the most conspicuous and well-studied expression of this is the location of the treeline, often defined as the poleward or seaward limit of coniferous forest. The correlation of the location of treeline with summer temperature is well known (Young 1989); and it is generally accepted that the location of the northernmost forests closely approximates the location of the 10°C isotherm for the warmest month of the year, July in most parts of the North. However, this is only a rough cor-

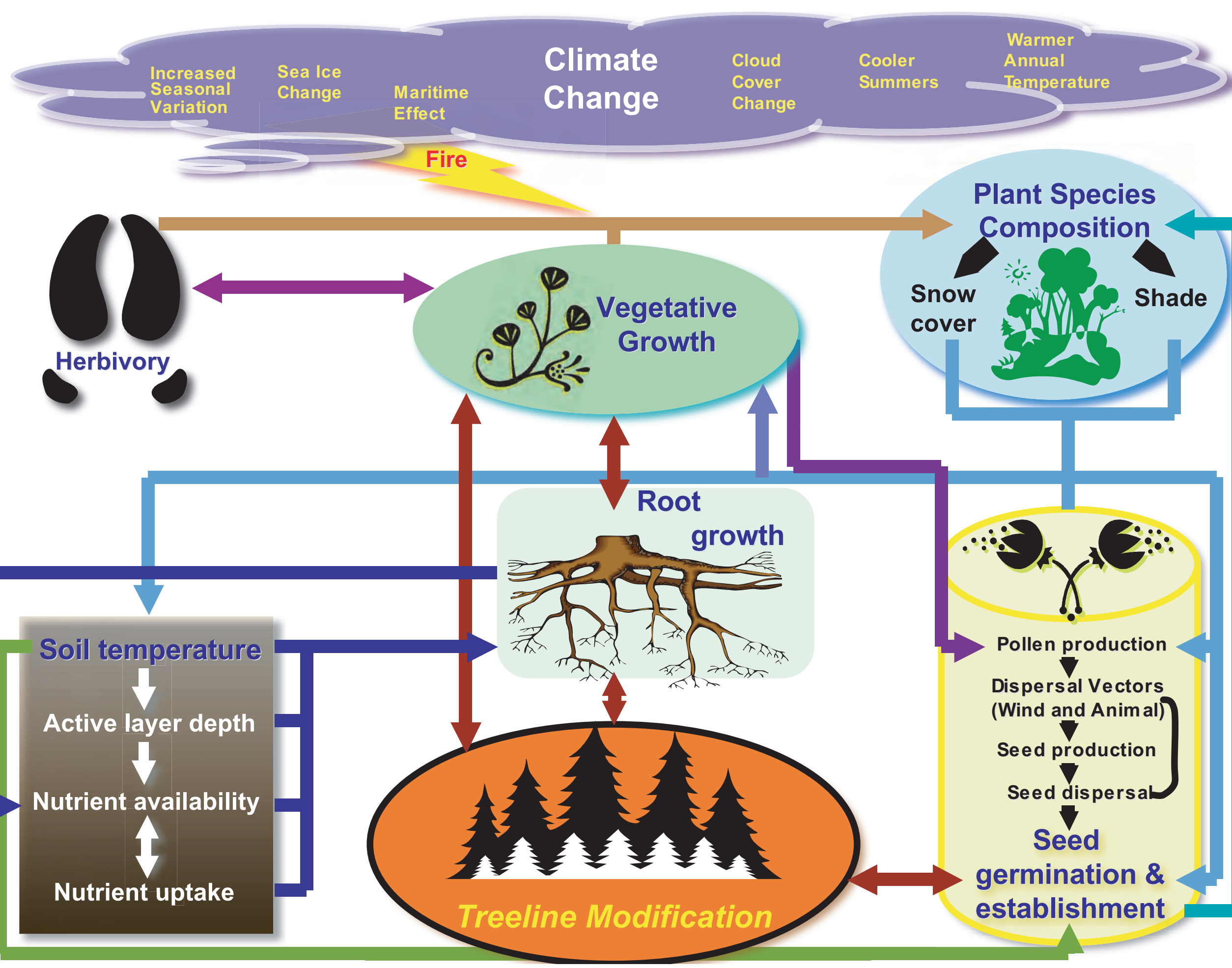


Figure 2.18. Biomechanics and feedback loops of treeline modification in relation to climate change

relation. The array of physiological processes that facilitate or limit the northward spread of certain tree species must take place at a microclimatic level, there may be more than a single set of limiting factors, and different sets of factors may be operating under different climatic conditions and in different geographic areas.

For example, the limiting factor in some situations might be the production of viable seed, which would require certain conditions of intensity and duration of warmth in the upper portions of mature trees during the growing season. On the other hand, germination and establishment of seeds might be the weak link in the chain, in which case temperatures at the soil surface would probably be critical. In this case, factors such as depth and duration of snow cover and/or shade from nearby mature trees might become dominant in determining success of reproduction and, over time, the advance or retreat of the forest. An additional complexity, of course, is the consideration that necessary conditions need to be met only often enough to allow successful reproduction occasionally during the long life span of plants such as conifer trees. Thus, a cooling but unstable climatic regime with an occasional unusually warm summer could conceivably facilitate the spread of trees more effectively than a slightly warmer but more stable climate.

Even this brief consideration of one type of distribution pattern points out the complexity of factors that are implicated in controlling the advance or retraction of the ranges of plants and animals. It will be noted that we have not mentioned the role of dispersal mechanisms and their effectiveness. These would presumably have little relevance with respect to current treeline trees, but the spread of some other organisms could be quite dependent on effective dispersal mechanisms.

Finally, we might note that the presence or absence of conspicuous organisms such as forest trees is easily established, and the changes in their distributions can be monitored by such means as aerial photography. Even ancient ranges can be provisionally plotted on the basis of fossil evidence. This becomes only somewhat less true in the case of species such as shrub birch (*Betula glandulosa* and related forms) or the various willows that comprise the overstory of the riparian shrub communities. In the case of less conspicuous species, such as tussock-forming cottongrass (***Eriophorum vaginatum***), only careful, on-the-ground studies may be able to show its presence or absence or its advance or retreat.

Equally important, changes in the distribution of a species such as the above could occur either by migration along a broad front or by the expansion of small, isolated, perhaps relict colonies outside the “normal” range of the species. Under the latter situation, range extensions could be expected to occur much more rapidly in response to changing climate or other environmental changes.

In spite of the complexity noted above, alterations in the distribution of various species and communities can be expected to lead to some of the most powerful concepts and tools with which to monitor the trajectory of overall environmental changes and of the “health” of the environment in general. We have concentrated here, and in the accompanying diagram, on plant species and some of the factors and interactions that can be involved in changes in distribution. In some cases, the migration and range extension of certain vertebrates and invertebrates would be dependent on the spread or retreat of vegetation types. This is probably at least partially the case, for example, in the spread of moose into arctic Alaska over the past couple of centuries. In other cases, especially in highly mobile species such as some migratory birds, the correlation between range changes and climatic or other environmental change is difficult to address successfully. Studies addressing these issues will probably be important in any long-term monitoring program in our study area.

2.7.3 Conceptual Framework for Thinking About Biodiversity in the Arctic Network

The National Park System plays a critical role in the preservation of biodiversity. ARCN parklands contain many of the Arctic's unique ecosystems intact, making the parks critically important to species survival. Biodiversity in the Arctic must be considered from a different perspective than in temperate and tropical regions (Figure 2.19). For most groups of organisms, the number of species found in a given area is only a fraction of the number that would occur in a comparable space in lower latitudes. For example, the boreal forest of northwestern Alaska may contain no more than a half-dozen tree species. Of these, one, white spruce (*Picea glauca*), may outnumber all other tree species by a wide margin over enormous areas. Large herbivores may be only two to four species (caribou and moose, with muskox and Dall's sheep in some locations).

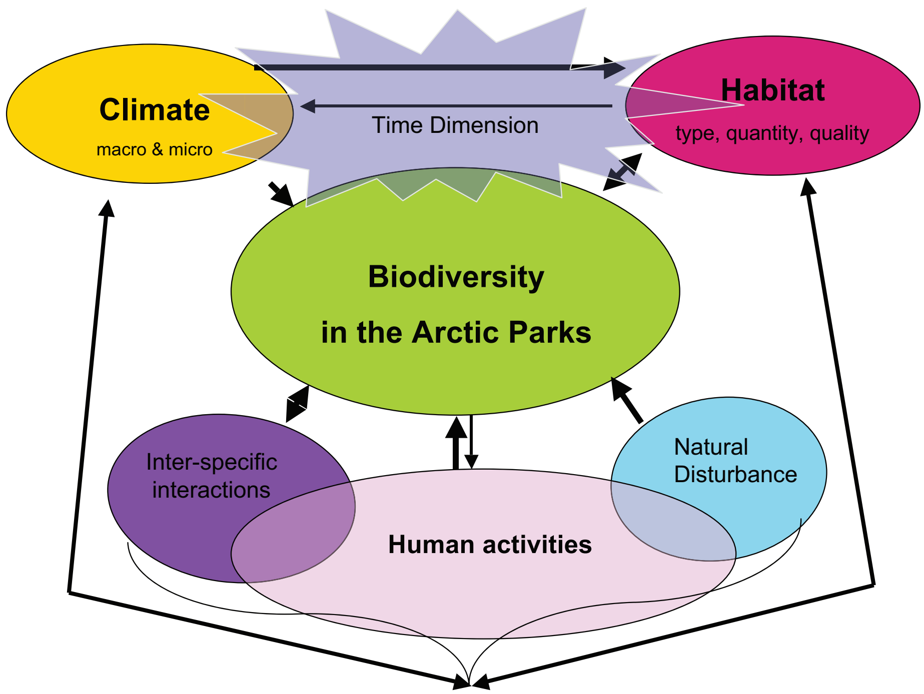


Figure 2.19. Biodiversity in the arctic parklands

Many of the species that do occur in the Arctic are of extraordinarily broad distribution. White spruce dominates the boreal forest from western Alaska to eastern Newfoundland, while both caribou and moose, as well as wolves and brown bear, have completely circumpolar ranges. This is also true for many smaller vertebrates, as well as many of the important species of higher plants, mosses, and lichens.

This would suggest that biodiversity in high northern latitudes is low, and that many of the species are so widespread as to be buffered from the effects of local events and processes that could negatively affect their populations. In fact, the situation is much more complex. While the "fragility" of the arctic environment has probably been overemphasized, there are a number of aspects of arctic ecosystems, at all scales, that lead to a high level of vulnerability.

Arctic ecosystems are unusual in that they often are reconstituted in a major way over relatively short periods of time. For example, an area of tundra that one year has a high population of microtine rodents, which are preyed upon by a array of predators such as snowy owls, jaegers, and arctic foxes, may, only a year later, be almost devoid of small mammals. This, of course, disrupts the entire predator-prey relationship; the predators may migrate elsewhere or cease to breed for that year. Similarly, the nutrient/fertility relationship between small herbivores and plants may be radically altered from year to year. Similar situations may occur in the case of large herbivores such as caribou, whose numbers may fluctuate wildly over periods of only a few years. At various points in these cycles, especially at the time they "crash," relatively minor changes in other aspects of the environment may make the difference between a fairly rapid recovery and an extended decline.

In many cases, the causes of population declines are poorly understood. The most spectacular examples are found in marine mammals, such as in the precipitous loss of a major proportion of the populations of sea otters, fur seals, and Steller's sea lions in the southern Bering Sea. Something similar has happened to several species of waterfowl, such as spectacled eider and emperor goose.

There are, of course, major changes in the arctic ecosystem from season to season. During the winter, many areas may have a resident bird population of less than a half-dozen species (e.g., rock and willow ptarmigan, gyrfalcon, and raven) while in the summer the number might swell to 50 or more species breeding within an area of a few square kilometers. Both the array of species and the numbers of individuals may vary significantly from year to year, as may breeding success.

It is important to keep in mind that the arctic ecosystem is very young in terms of geologic time. Most of the North American Arctic was under ice within the last 8,000 to 12,000 years. In glaciated areas, the entire biota has had to be rebuilt by migrants from afar since the end of the last Ice Age. In many cases, it appears that the process is still incomplete. Grizzly bears, for example, have yet to colonize the eastern Canadian Arctic successfully. The biodiversity of large regions of the North American Arctic have yet to stabilize after the retreat of the ice.

It is interesting that ARCN lies within a zone of contact between the recently deglaciated North American Arctic and the much less heavily glaciated, and thus in some senses much more ancient, Asian Arctic. Much of BELA, CAKR, NOAT, and KOVA were not glaciated in the later Pleistocene and were essentially a part of the Asian Arctic, connected by the dry land of the Bering Land Bridge. Thus, these areas both share some of the ancient aspects of arctic Asia and have also served as migratory pathways for the recolonization of the glaciated lands to the east. As a result of this unusual history, the lands within ARCN often have a higher level of diversity of such organisms as vascular plants, small mammals, and insects, compared to other parts of the North American Arctic. Not only are there a certain number of endemic species, but there are often isolated populations of rare species and communities of unusual species and combinations of species. In addition, Asian species, at least of birds, seem to still be actively colonizing the western Alaskan Arctic. Examples are white wagtail and arctic warbler. Some sea birds, such as black guillemot, are also actively changing their ranges.

While biodiversity issues are complex throughout the entire Arctic, it is safe to say that this is especially true within ARCN. There are more species of many groups of organisms, their population and community structure is more variable, and changes appear to be more rapid than in many other parts of the North. It is important to recognize that many of these local peculiarities are poorly understood and poorly documented at this time. There is no question that many additional examples will come to light as more research is done within ARCN. We are still in the early stages of gathering baseline data on the components and nature of the ecosystems represented in ARCN, and this basic enumeration of the biodiversity of the region will continue far into the future.

2.7.4 Changes in Biogeochemistry in the Arctic Network

Ecosystem-level response to human-induced disturbance in the Arctic can be tracked by monitoring shifts in net primary productivity (NPP) and cycling of carbon (C), nitrogen (N), and phosphorus (P). Focusing on the biogeochemistry of the boreal and tundra regions will elucidate the underlying links and feedbacks between biogeochemical cycling, changes in species composition, and landscape-level consequences of these changes (Figure 2.20).

The tundra and boreal biomes represented in the Arctic Network parks contain large reservoirs of C, N, and P. High-latitude terrestrial soils contain from 20 to 45 percent of the global pool of soil organic C and only a small percentage of total soil N and P contained therein is available for plant uptake. These reservoirs have accumulated as a result of slow rates of nutrient cycling in large areas of these biomes, which are dominated by continuous permafrost. The "active" soil layer of these permafrost-dominated ecosystems have characteristically low temperatures and high moisture content. This leads to slow or no decomposition of soil organic matter (SOM) that lies largely below annual thaw depth. Therefore most of the nutrients in these reservoirs are not available for plant uptake. Resultant nitrogen and phosphorus limitation of plant growth in arctic and subarctic regions has been well documented.

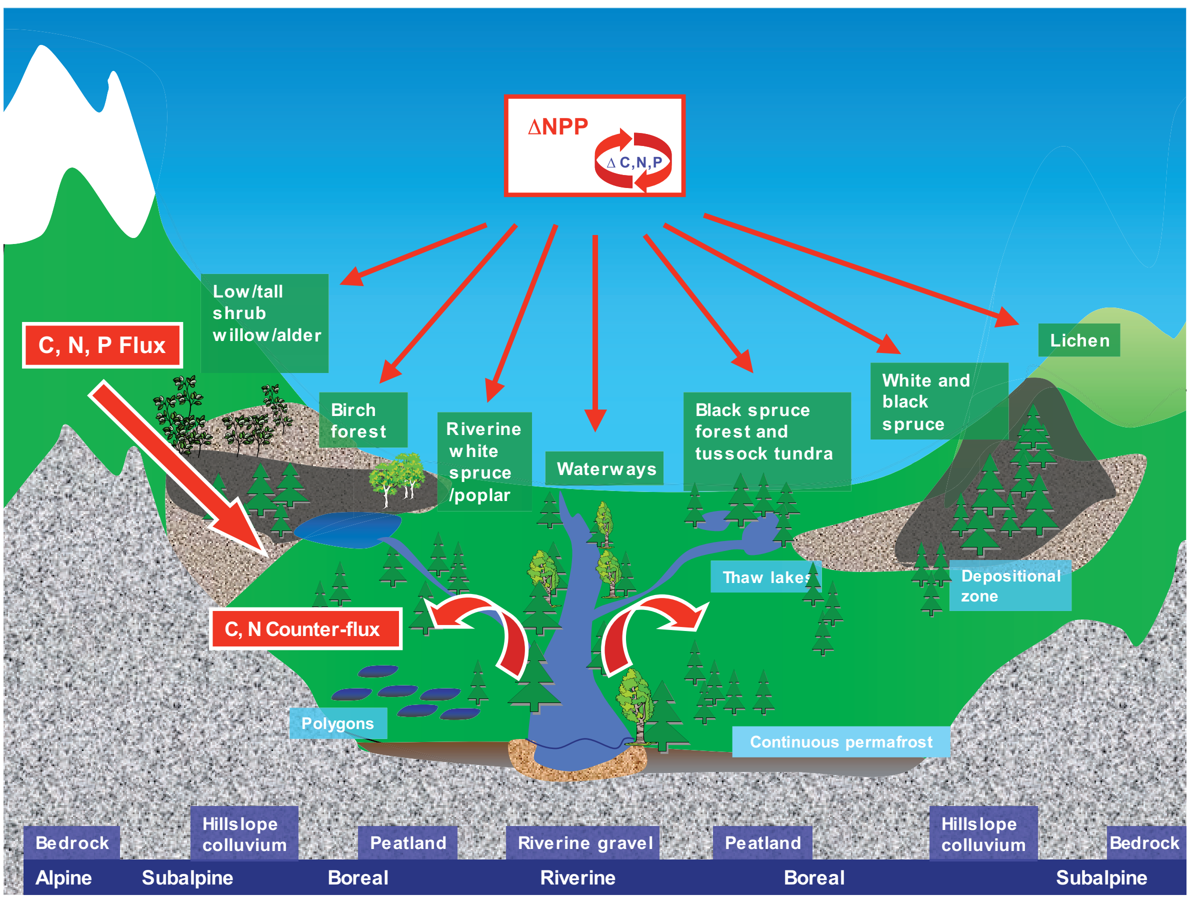


Figure 2.20. Ecosystem-level response to anthropogenic disturbance can be tracked by monitoring shifts in net primary productivity (NPP), cycling of carbon (C), or flux of nitrogen (N) and phosphorus (P).

One of the main ecosystem drivers in the Arctic is climate. Much evidence shows that temperatures are steadily increasing in arctic regions. Ambient temperatures in northwest Alaska have increased since 1950 (Stottlemyer 2001). This may be associated with increased soil active layer depth and permafrost depth which may in turn be linked to altered soil moisture, soil temperature, SOM decomposition and soil respiration rates. Expected higher soil temperatures may alter rates of N mineralization, dissolved organic carbon (DOC), and dissolved organic nitrogen (DON) release and subsequent transport to aquatic systems. This additional input of carbon and nitrogen to freshwater and coastal ecosystems could have an effect on the overall nutrient balance of aquatic ecosystems in ARCN. Tracking the large-scale effects of changing climate on the boreal and tundra biomes will require in-depth investigation of current and future relationships between soil conditions and SOM as well as other element cycles, specifically N.

Physical changes in the landscape caused by increased temperatures could also have ecosystem-level consequences in ARCN parks. For example, increased temperatures would likely cause increased development of thermokarsts, depressions caused by selective thawing of ground ice or permafrost. The additional input of C, N, P and trace elements to aquatic systems from thermokarst areas could have far-reaching effects on the biological community. Understanding the relationship between large-scale physical changes to arctic park ecosystems and the coupled chemical and biological processes will be crucial to monitoring ecosystem-level change in ARCN.

Increased ambient temperatures may also directly stimulate primary production to some extent but it appears to be more likely that increased growth is primarily a factor of higher rates of N mineralization and therefore availability. Changing climate and associated factors have already resulted in increased tree growth and associated advancement of treeline into the tundra biome (Figure 2.18). Ecosystem-scale monitoring may be necessary to elucidate such patterns.

2.7.5 Potential Pathways and Ecosystem-level Consequences of Air Pollutants in Arctic Parklands

Air toxins, such as mercury and persistent organic pollutants, are produced by a variety of sources. These can be point sources, for example from a power plant, metal smelter, or pool of spilled oil, or much more diffuse nonpoint sources, for example vehicles whose emissions vary in location depending on where the car is being operated. These sources may be close to (e.g., Red Dog Mine), or far away from (e.g., Russia and China) ARCN parklands. The emissions from these sources can be emitted directly into the atmosphere (for example out of a power plant stack), or can be introduced into the atmosphere through the volatilization of a compound released into the soil or water (such as the volatilization of light hydrocarbons from an oil spill). Once the emissions have been produced, they can be transported to the parks through global and local circulation patterns. Two good examples of this are the transport of Russian pollution into the arctic parks in winter (Arctic Haze) and the transport of Chinese dust and pollution into the Arctic in spring.

Air toxins can influence the ARCN parklands through a variety of mechanisms (Figure 2.21). The toxins can directly impact geophysical processes or can enter the ecosystem through deposition and then impact biological/biochemical processes. For example, air toxins can change the observed atmospheric geophysical properties by changing the albedo (the reflectivity of the earth's surface and atmosphere to solar radiation) over the parks, changing the frequency and types of clouds occurring in the region, and changing the frequency of precipitation. These effects change the amount of solar radiation and precipitation reaching the surface. This could lead to an increased growing period (if the cloud amount decreases and more sun reaches the surface) or a decreased growing period (if the precipitation pattern changes to more precipitation during winter and higher snow depths). In addition to these direct geophysical effects, the transported toxins can also be deposited to the parks' ecosystems through dry deposition (settling) or wet deposition (precipitation). As the toxins accumulate in the ecosystems, they can cause a variety of biological responses. Among these responses are the

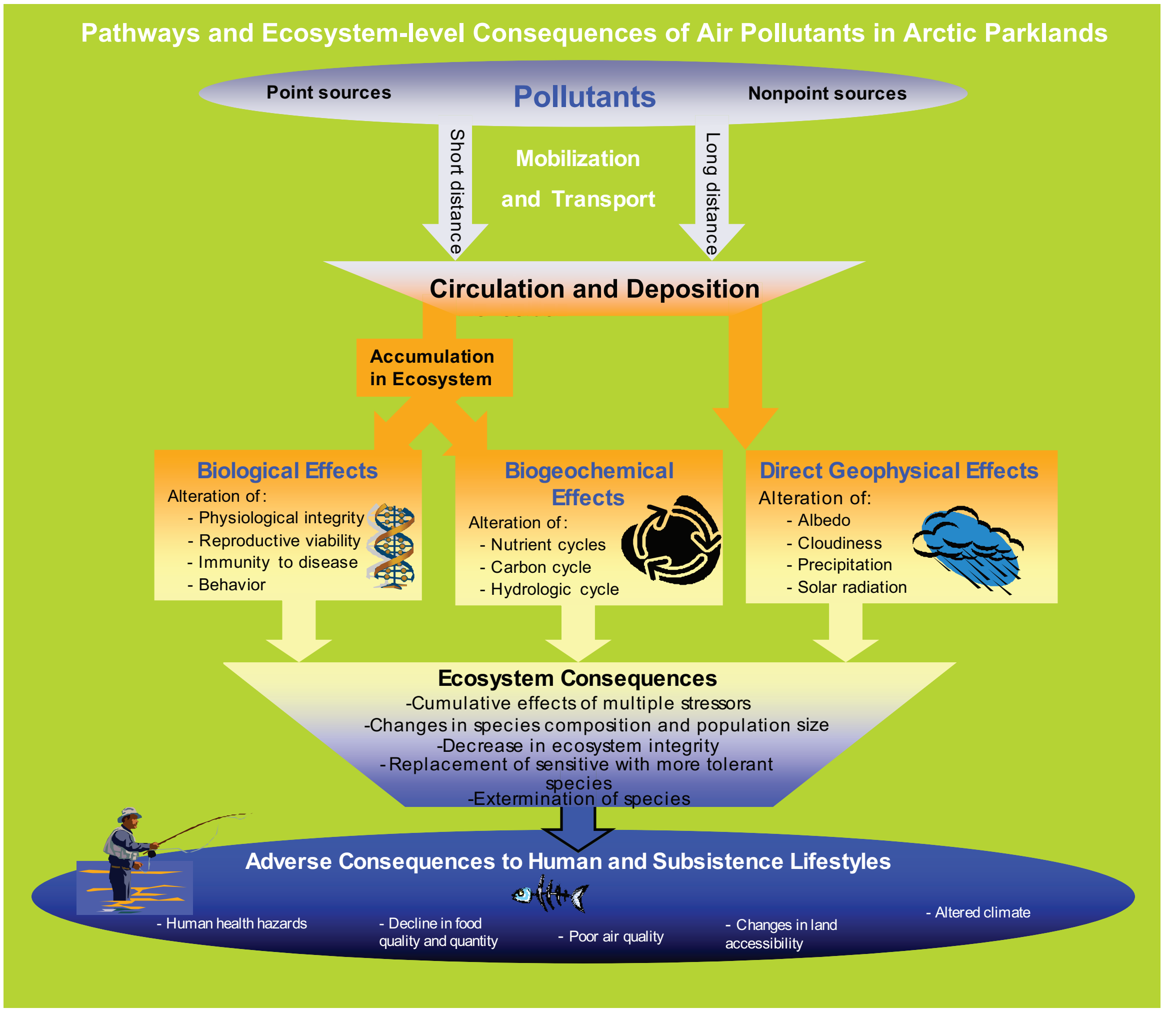


Figure 2.21. Potential pathways and ecosystem-level consequences of air pollutants in arctic parklands

alteration of physiological integrity, reproductive viability, resistance to disease and behavior. All of these effects can make plants and animals more susceptible to changes in their ecosystems and potentially less viable. The toxins can also have biogeochemical effects, altering nutrient cycles, energy and carbon cycles, and hydrologic cycles. These effects can be cumulative, especially if multiple stressing mechanisms are involved. The overall effects of multiple ecosystem stressors could include changes in species composition and population size (e.g., more moose and fewer caribou), decrease in ecosystem integrity (e.g., making plants less able to adapt to a changing climate), replacement of sensitive with more tolerant species (such as a replacement of tundra with shrubs), or the extirpation of species or communities (e.g., alpine wetland communities).

Humans and their subsistence lifestyles are also directly impacted by these air toxins and their effects. Some of these toxins are human health hazards and increased exposure to the toxins should lead to increased morbidity. Mercury is a prime example of an air toxin that could lead to adverse health effects in humans living in the Arctic. The air quality in the parks could also deteriorate quality and quantity of food sources. The availability and quality of subsistence foods could deteriorate due to increased stress on terrestrial and aquatic ecosystems, causing changes in habitat, migration patterns of subsistence species, or overall decreased numbers of desired food species. The accessibility of the land may also change if precipitation patterns, melt/thaw periods, etc. change due to alteration of geophysical processes and hydrological cycles. This would impact subsistence lifestyles by decreasing the accessibility of food species. For example, it is much harder to hunt caribou in soggy tundra than on a solid snow surface. Lastly, climate change may be exacerbated by the air toxins through the increased trapping of heat by greenhouse gases and low-level cloud cover. This could have dramatic effects on the people and animals of the ARCN parklands. The changing climate could lead to changes in ecosystem type, animal viability, land accessibility, etc. that could make a subsistence lifestyle based on the ARCN parks' resources untenable.

2.7.6 A Conceptual Framework for Considering Migratory and Invasive Species of the Arctic Network

Invasive species are those which have changed their distribution and colonized new areas. Current examples within ARCN would be various weedy plants that have established themselves in disturbed areas near villages and along roads. Invasive species can also be native species that have increased their populations and impact on native ecosystems to an important degree. The enormous and destructive rise in bark beetle populations in the spruce forests of southcentral Alaska is a good example of this. Both of these types of situations exist, generally on a small scale, within ARCN. Another common phenomenon, especially in northern environments, is the cyclical rise and fall, often by an order of magnitude or even much more, of populations of native species. While the classic examples of this are various microtine rodents (voles and lemmings) it also occurs in other species, including caribou. There are also migratory species whose breeding location and population status may change radically over time. Several species of Siberian birds (e.g., white wagtail) have colonized western Alaska in recent decades. The known examples of invasive species are mostly conspicuous organisms, but it is probable that invertebrates and certain plants will be found to show similar changes in distribution.

Invasions by "foreign" organisms usually depend on much more than simply the opportunity provided by an unusual (usually anthropogenic) dispersal event. Generally more important are changes in the local environment that allow individuals or propagules from the invasive organisms to establish themselves in areas from which they were previously excluded by ecological conditions. These can be simple changes such as the disturbance of the soil surface, encouraging the growth of ephemeral weeds, or complex alterations in the environments brought about by changing climate. These latter owe much of their complexity to the fact that they are seldom straightforward. The ultimate effect of a climatic change may result from an array of factors: changes in competition or predation as other species are eliminated or favored, changes in precipitation and/or hydrology and permafrost regime that favor certain species, or changes in soil chemistry due to human activities that inhibit otherwise common species and thus provide a habitat with reduced competition for resistant species.

Some "invasions" are actually the reestablishment of species that had previously been reduced or extirpated. Muskoxen in western Alaska are a good example. Others seem to be natural reexpansion, such as the case of grizzly bears on the Seward Peninsula in recent decades. Many of these population reestablishments or expansions are actively encouraged by managers, as for example, the efforts to encourage waterfowl such as emperor geese and spectacled eider along the Bering Sea coast.

When viewed in the above context, it should be clear that invasive species, or changes in the distribution and abundance of species, are not only of intrinsic interest but are also likely to be important bellwethers in identifying deeper, more profound, and widespread changes in ecosystems (Figure 2.22). They can be expected to be of great significance in the construction of monitoring programs.

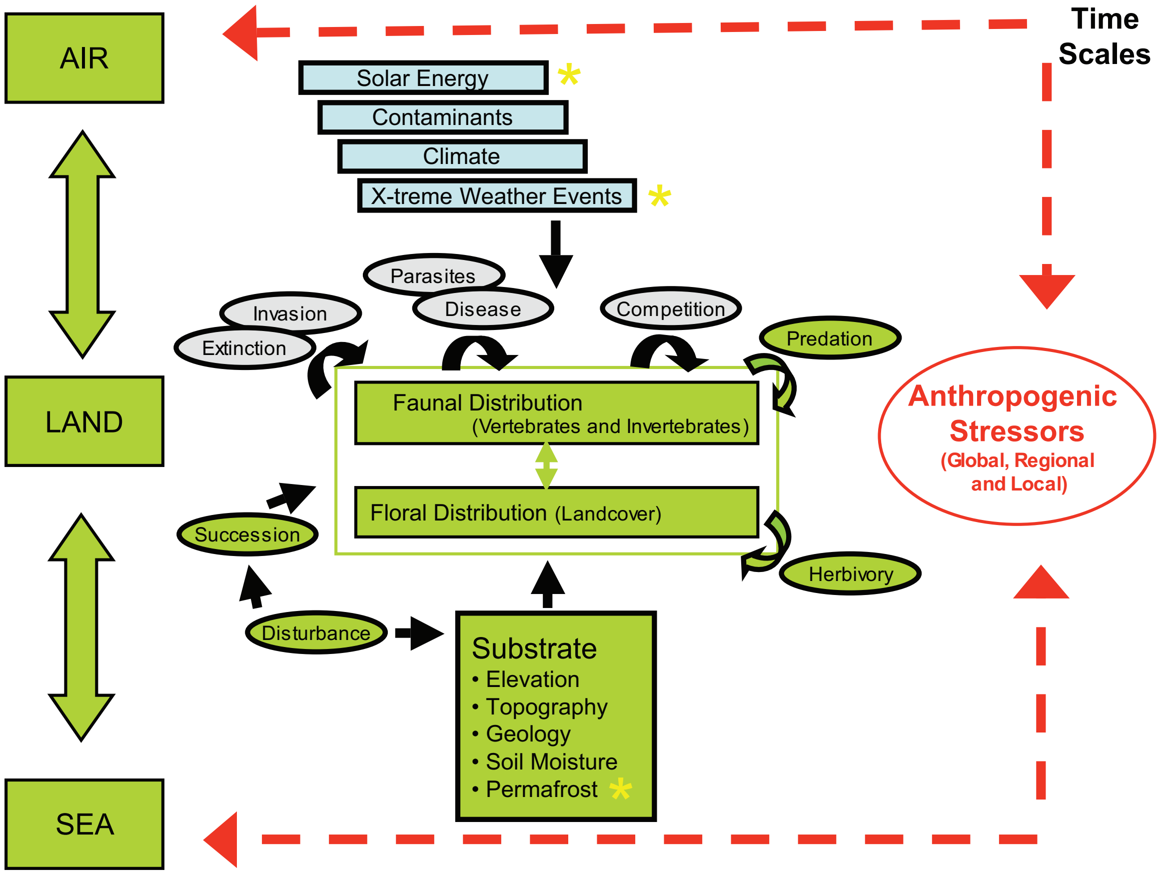


Figure 2.22: A graphic representation of the complex of factors that may be involved in changes in distribution of migratory and invasive organisms over time in ARCN.

2.7.7 Invasive Species Pathways in ARCN

Although environmental factors are likely to be primary in determining the fate of an invasive species, the importance of dispersal routes and mechanisms should not be overlooked (Figure 2.23). In many cases, of course, a dispersal route also represents an area of environmental alteration. The berms of a gravel roadbed, for example, will normally have very different drainage and soil characteristics from the surrounding unaltered environment. A roadbed may then provide a highway for the spread of weedy species far beyond their normal range. Even a trail that is regularly used by ATVs or snowmobiles may have a similar, although usually less marked, effect.

Even low-impact recreational activities can provide dispersal opportunities for exotic organisms. Camping gear can transport seeds, the floats and hulls of amphibious aircraft can transport propagules of plants from lake to lake, and canoes and kayaks can effectively move plants down a river drainage. The following diagram shows some specific examples of how plants and animals might move about as a result of human activities.

Figure 2.23. Examples of possible routes and vectors for the dissemination of exotic species within ARCN. Red lines are existing or proposed (RS 2477) roads or trails.

Chapter 3
Selection and Prioritization of Vital Signs

"The ecosystem is greater than the sum of its parts"—Eugene Odum (1964)

3.1 Introduction

Vital signs monitoring is the preeminent function of the Inventory and Monitoring Program. The Inventory and Monitoring Program has defined vital signs as a set of "selected physical, chemical, and biological elements and processes of park ecosystems that represent the overall health or condition of the park, known or hypothesized effects of stressors, or elements that have important human values" (http://science.nature.nps.gov/im/monitor/). Vital signs are a subset of the natural resources that the National Park Service is mandated to preserve "unimpaired for future generations."

Vital signs monitoring is a key component in the National Park Service's strategy to provide scientific data and information for management decision-making and education. Vital signs also contribute information needed to understand and measure the condition of watersheds, landscapes, ecosystems, communities, and species of interest. Monitoring data help to define the normal limits of natural variation in park resources and provide a basis for understanding observed changes and possible management connections.

The Vital Signs Monitoring Program reports directly to two strategic planning goals (Goal 1b3A, Vital Signs Identification, and Goal 1b3B, Vital Signs Implementation) and provides data and information systems needed to report to several other DOI goals (see Table 1.1).

Defining, evaluating, and choosing measurable ecosystem attributes that will best meet land management objectives is no small task. In this chapter we describe the process we used to identify, select, and prioritize vital signs for ARCN.

3.2 Vital Signs Selection

Our list of vital signs represents the culmination of a three-year process (Table 3.1). The selection process began in October 2003, when the network coordinator traveled to park headquarters to meet with park staff from each of the park units to (1) learn what monitoring initiatives were currently underway in the parks; (2) discuss potential stressors and possible implications for park resources; and (3) develop an initial list of vital signs that might serve as "indicators of change" for park resources.

Table 3.1. Timeline for the selection and prioritization of vital signs for the Arctic Network

Date	Event/Milestone	Participants	Products
October–November 2003	Park scoping mini-workshops (2)	Entire park staff in each of the five units	Exhaustive list of stressors and potential vital signs of interest to parks
October 2004	ARCN fully funded and operational	—	—
June 2004–August 2005	Freshwater, Coastal and Terrestrial scoping workshops	Technical Advisory Committee + additional experts in the field of arctic ecology	Scoping notebooks, monitoring objectives, conceptual models, further development of potential vital signs list, and initial list of potential measures
April–July 2005	One-on-one personal interviews with past & present superintendents (6)	Superintendents + ARCN coordinator	Superintendent priorities for the program and key vital signs of interest
September–October 2005	Arctic Network staff reorganize vital signs into national framework	ARCN staff	Initial vital signs list and draft measures
25 October 2005	Technical Committee develops criteria for vital signs selection	Technical Advisory Committee	Ranking criteria for prioritization of vital signs
December 2005	Initial web-based ranking of vital signs	Technical Advisory Committee + invitees to the LAW workshop	Web-based ranking of vital signs completed
11–13 January 2006	Land-Air-Water (LAW) Workshop, including reprioritization of vital signs using several methods	Technical Advisory Committee + superintendents + additional outside experts in the field of arctic ecology	Vital signs and potential measures for each further developed
March–April 2006	Series of working group and technical committee meetings (4)	Reorganization and prioritization of vital signs	Vital sign description pages with suggested measures completed
23 May 2006	Technical Committee meeting to select vital signs	Selection of vital signs	Final recommended vital signs list
June–August 2006	Individual meetings with each park superintendent to discuss vital signs list	Superintendents + ARCN coordinator	Approved vital signs list
January 2007	State of the Arctic Parks (SOAP) meeting	Park staff and cooperating investigators	Goal is to report back to park managers, link vital signs, and foster collaboration

Park-specific lists of potential stressors and an initial list of species, communities, and ecosystems that might be good indicators of change were compiled based on discussions from these meetings.

Input from park managers is critical to the success of the ARCN long-term monitoring program. To facilitate the process of gathering information on natural resources of concern and to further develop the potential list of vital signs, the ARCN coordinator met with several past and current park superintendents of the five arctic parklands between June and August of 2006 (Appendix 1). Before the park scoping workshops and superintendent interviews were complete, differences in resource management priorities among the five parks were perceived as the greatest challenges facing the network. Subsistence and visitor use, for example, were not initially perceived as having the same importance among individual parks. However, as we examined potential issues during our park scoping workshops and superintendent interviews, we found that actually the ARCN parks do share similar resource management concerns and monitoring needs. Our scoping process revealed that broader issues, for example global climate change and accumulation of globally derived pollutants, were as important as subsistence and visitor use to park management. We determined from our scoping process that there is, in fact, much overlap of similar resource management concerns among Arctic Network parks.

Shortly after the Arctic Network received its operational budget for monitoring, network staff held a series of scoping workshops to provide a forum for NPS resource managers and scientific experts to discuss ideas for building a statistically sound, ecologically based, management-relevant, and affordable monitoring program for the Arctic Network. Each of the workshops focused on one of the three major ecosystem types in ARCN: freshwater, coastal, and terrestrial ecosystems, which were roughly based on "The State of the Nation's Ecosystems" report (H. John Heinz Center, 2002). Although we realize this division is somewhat arbitrary, it enabled us to strategically separate ARCN ecosystems into more manageable subunits for the purposes of discussion and stay consistent with other national-level initiatives. One of the main goals of each of the workshops was to identify potential vital signs and possible measures of those vital signs. (See Appendices 1–6 of *Monitoring Ecological Change in the Arctic Parklands: Vital Signs Monitoring Plan for the Arctic Network, Phase 1 Report*, available at <http://www1.nature.nps.gov/im/units/arcn/documents/index.cfm>, for more detail). The combined list of vital signs that emerged from the first three scoping workshops contained 81 vital signs of interest to the parks.

In the fall of 2005 the ARCN staff reorganized our monitoring objectives, vital signs, and list of potential measures into the national framework in preparation for our fourth and final workshop, the Land-Air Water (LAW) Linkages Scoping Workshop. In addition, the Technical Advisory Committee met and developed the ARCN vital sign selection criteria (Table 3.2), which was used to rank vital signs using a web-based process, before the LAW workshop. Participants in the LAW workshop included park superintendents, the technical advisory committee, and a subset of the invited experts from the previous three workshops.

Decision-making is a complex process whereby alternatives are evaluated based on knowledge, intuition, emotion, and logic. In order to facilitate a rational rather than an emotional or intuitive approach to vital sign ranking and selection, we built a web-based vital sign ranking tool, based on uniform criteria, that each participant could use before the LAW workshop (Figure 3.1). This tool would allow much of the personal intellectual work to be done before the workshop, before any group decision making processes would occur. The tool also ensured that each participant had the opportunity to objectively weigh each potential vital sign against our suite of criteria (Table 3.2). The results were tallied, and they provided an efficient starting point for discussion at the workshop. The participants selected 48 vital signs after redundancy was removed and related indicators were merged under a single vital sign.

Table 3.2. Selection criteria that land-air-water (LAW) workshop participants used to rank the draft vital sign list using the web-based program

1. **NPS, I&M and Park Mandates**
   - **Is the attribute ("vital sign") relevant to national and network goals?**
     [3 = highly relevant, 2 = somewhat relevant, 1 = not relevant]

2. **Ecological Significance and Scientific Validity**
   - **Is the attribute ("vital sign") relevant to ecosystem function or structure? How important is the attribute in controlling ecosystem function and/or structure?**
     [3 = high relevance AND importance, 2 = high relevance OR importance, 1 = low importance AND low relevance]
   - **Does the attribute ("vital sign") have linkages across ecosystems or system components? How closely linked is the attribute to other attributes and resources in the park?**
     [3 = many strong links, 2 = few strong links or many weak links, 1 = few weak links]
     • **Is the attribute ("vital sign") relevant at multiple spatial, temporal and hierarchical scales (e.g. – population, community, ecosystem, landscape scale)?**
     [3 = extremely useful at multiple scales 2 = somewhat useful at multiple scales 1 = minimally useful at more than one scale]

3. **Response Variability**
   - **Is the attribute ("vital sign") a sensitive indicator of change?**
     [3 = extremely useful, 2 = moderately useful, 1 = minimally useful]
   - **Will the attribute ("vital sign") detect change within a timeframe useful and appropriate for this monitoring program?**
     [3 = highly useful to detect change, 2 = moderately useful to detect change, 1 = minimally useful to detect change]

4. **Park Management Significance**
   - **How important is this attribute ("vital sign") for satisfying legal or policy mandates?**
     [3 = high importance (required or specifically identified; e.g. in enabling legislation), 2 = moderate importance and potentially supporting legal or policy mandates such as ecological integrity, 1 = low importance (could not help satisfy legal or policy mandates)]
   - **How important is the attribute ("vital sign") for managing a resource of high priority for the park?**
     [3 = high importance, 2 = moderate importance, 1 = low importance]

The LAW workshop was held in January 2006. The purpose of the workshop was to reorganize and prioritize vital signs from earlier workshops and to link terrestrial, aquatic (freshwater, brackish, and near-shore), and air quality vital signs. In order to take a more holistic approach to selecting and prioritizing vital signs, this workshop set out to (1) determine priority monitoring questions and associated vital signs for long-term monitoring in ARCN; (2) discuss potential measures for those priority vital signs in the context of other related vital signs; (3) arrive at an overarching conceptual model that could be used as a framework for developing an integrated monitoring program; and (4) begin to discuss possible overarching sample designs for the ARCN monitoring program.

A good portion of this workshop was spent restructuring the vital signs for better integration with related vital signs. Because the vital signs were significantly rearranged by the end of the first day, the group decided to reprioritize the vital signs using the original ranking criteria. Most of the work that took place in smaller breakout groups on day two involved determining the exact metrics for monitoring the vital signs of particular interest to ARCN (Appendix 8). During this workshop, the group was asked to think practically about logistics and access issues in ARCN, and so much of the discussion took on a more practical feel.

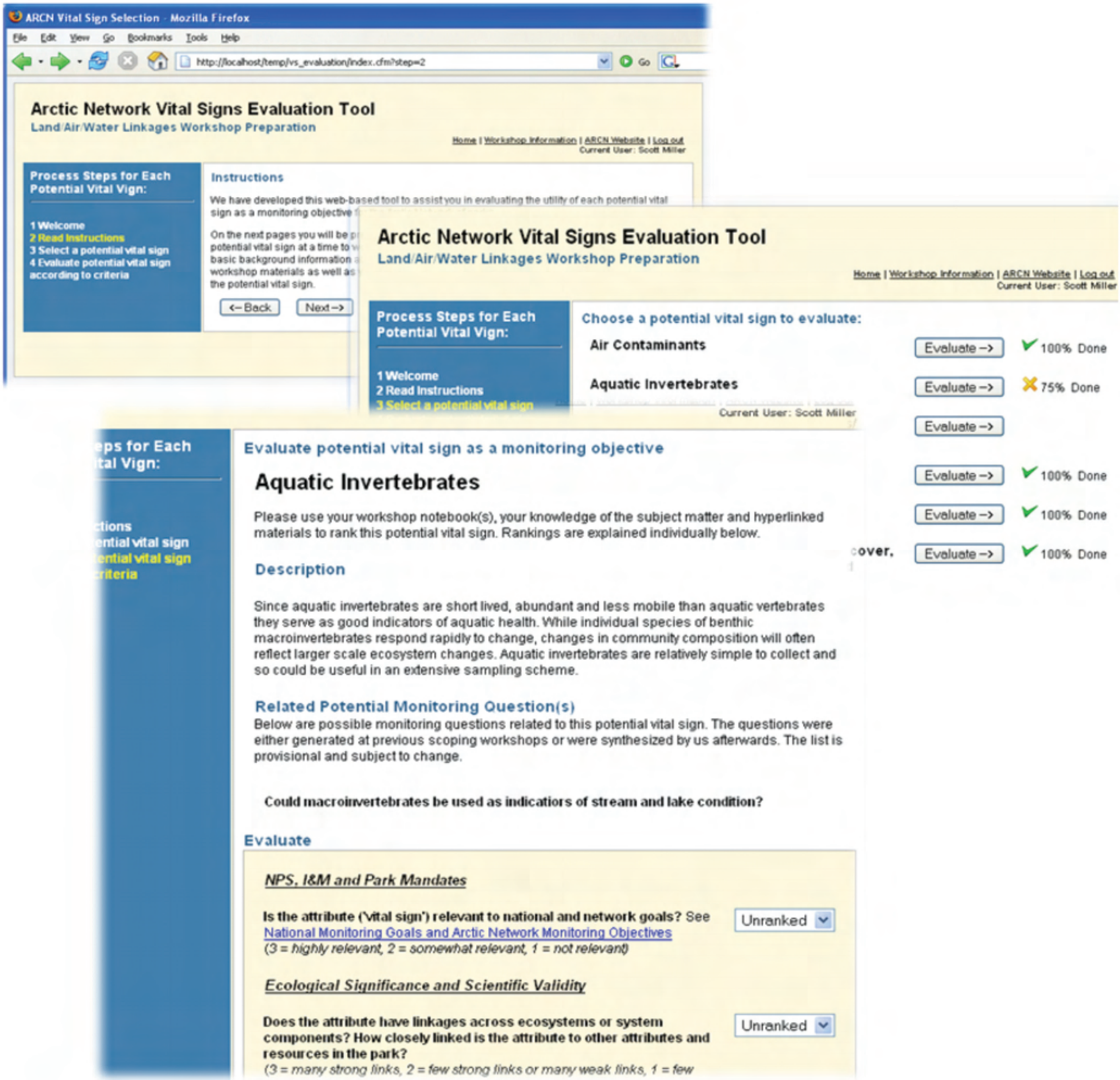


Figure 3.1. Selections from the ARCN web-based vital signs ranking tool that was used to rank vital signs before the Land-Air-Water Linkages (LAW) workshop

The LAW workshop gave participants from each of the first three workshops a chance to discuss seemingly disparate vital signs in a more holistic fashion. One of the outcomes from this workshop was the realization that many of ARCN's vital signs cross typical ecosystem boundaries (Figure 3.2). It was also clear by the end of this workshop that the Technical Advisory Committee needed to meet again to discuss particular vital signs that needed additional work for the ease of protocol development later.

In spring of 2006 several smaller working groups met to refine particular vital signs (Appendix 8). For example, by the end of the LAW workshop we had mammal assemblages as one of our top vital signs. In addition, we had developed an exhaustive list of large mammals of importance to the network and had identified a host of measures for monitoring; however, it was not clear which of the large mammal species would serve as the best indicators of change in ARCN. To determine this, a smaller working group was formed to discuss mammals and further develop vital signs descriptions for each one. The combined list of vital signs that emerged by the end of this reorganization process consisted of 39 vital signs. This final list of vital signs was reviewed and evaluated by the technical advisory committee to ensure consistency and clarity.

3.3 Vital Sign Prioritization

On May 23, 2006, the Technical Advisory Committee met to prioritize vital signs. This meeting was crucial to help ARCN identify the most important vital signs for initial protocol development. Network staff presented the revised vital sign descriptions (Appendix 8), the updated holistic model (Figure 3.2), and the final list of vital signs inserted into the national framework (Table 3.3). The group used a three-tiered approach for considering vital signs. The first tier of vital signs considered were those the committee thought were important to the network, but that park staff or other local, state, or federal agencies were already monitoring (Table 3.3). Much of the discussion focused on how ARCN can best access and use current data streams. Examples of vital signs in this tier include: (1) Caribou, which are currently being monitoring intensively by the State of Alaska; (2) Sea Ice, currently being monitored by the National Oceanic and Atmospheric Administration (NOAA); (3) Subsistence/Harvest, harvest data currently being collected by the Alaska Department of Fish and Game; and (4) Fire Extent and Severity, currently monitored intensively by the NPS Regional Fire Program (Table 3.3).

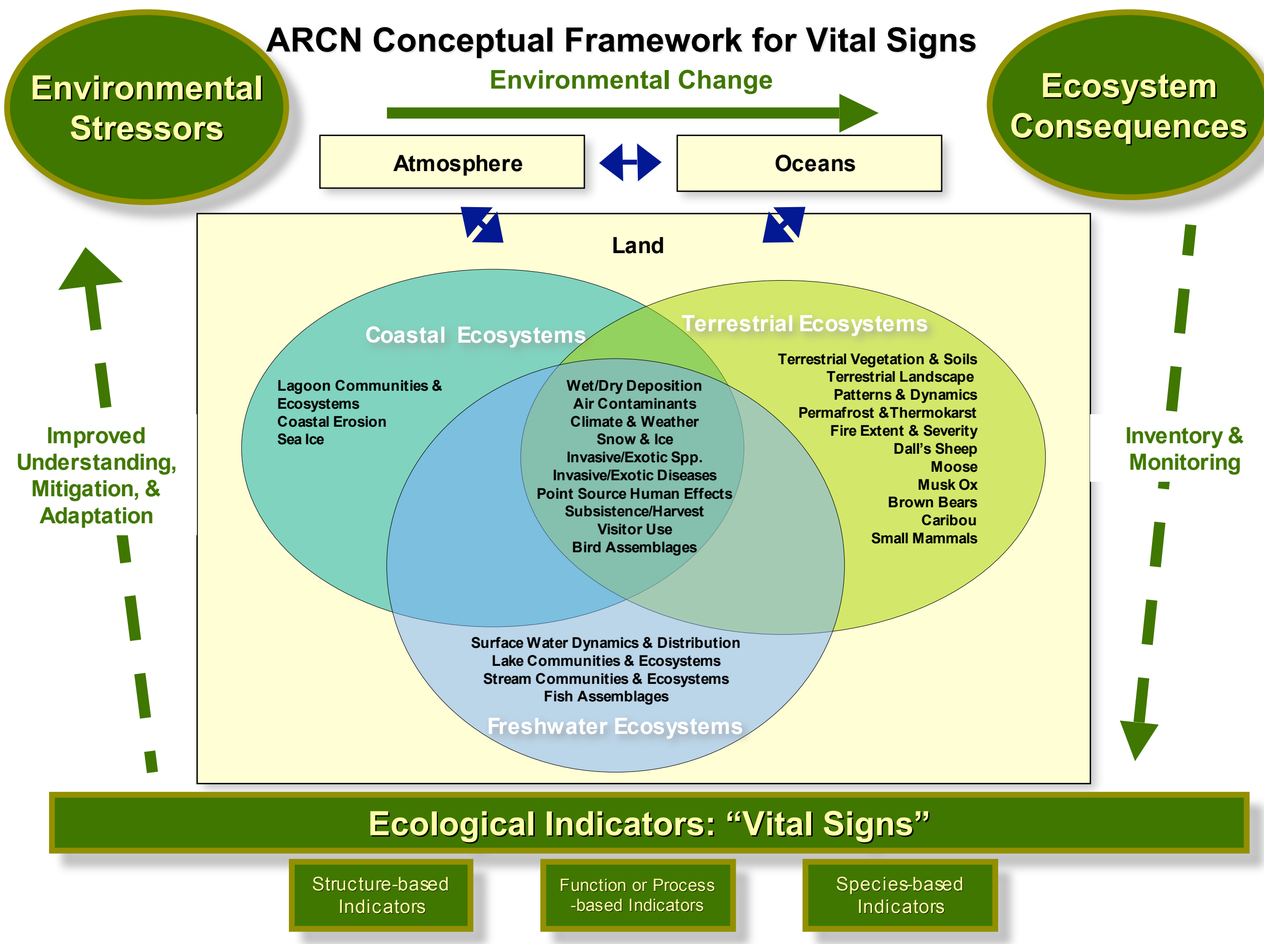


Figure 3.2. Vital signs of the Arctic Network in relation to the holistic model

Table 3.3. National Ecological Monitoring Framework with vital signs that ARCN is working on independently or jointly with a network park, federal, state, or private partner to develop and implement monitoring protocols

Arctic Network Ecological Monitoring Framework and Vital Signs								
Level 1	**Level 2**	**Level 3**	**ARCN Vital Sign**	**BELA**	**CAKR**	**GAAR**	**KOVA**	**NOAT**
Air and Climate	Air Quality	Wet and Dry Deposition	Wet and Dry Deposition	†	†	†	†	†
		Air Contaminants	Air Contaminants	†	†	†	†	†
	Weather and Climate	Weather and Climate	Climate and Weather	†	†	†	†	†
			Snow and Ice	†	†	†	†	†
Geology and Soils	Geomorphology	Coastal/Oceanographic Features and Processes	Coastal Erosion	†	†	–	–	–
			Sea Ice	•	•	-	-	-
	Soil Quality	Soil Function and Dynamics	Permafrost\ Thermokarsting	†	†	†	†	†
Water	Hydrology	Surface Water Dynamics	Surface Water Dynamics and Distribution	†	†	†	†	†
	Water Quality	Water Chemistry	Lagoon Communities and Ecosystems	†	†	-	-	-
			Lake Communities and Ecosystems	†	†	†	†	†
			Stream Communities and Ecosystems	†	†	†	†	†
Biological Integrity	Invasive Species	Invasive/Exotic plants	Invasive/Exotic Species	•	•	•	•	•
	Infestations and Disease	Animal Diseases	Invasive/Exotic Species	•	•	•	•	•
	Focal Species or Communities	Fishes	Fish Assemblages	†	†	†	†	†
		Birds	Bird Assemblages	†	†	†	†	†
		Mammals	Brown Bears	†	†	†	†	†
			Caribou	•	•	•	•	•
			Dall's Sheep	–	–	†	†	†
			Moose	•	•	•	•	•
			Musk Ox	•	•	•	–	•
			Small Mammal Assemblages	†	†	†	†	†
		Terrestrial Complex (use sparingly)	Terrestrial Vegetation and Soils	†	†	†	†	†
Human Use	Point-Source Human Effects	Point-Source Human Effects	Point Source Human Effects	–	•	•	–	–
	Consumptive Use	Consumptive Use	Subsistence/Harvest	•	•	•	•	•
	Visitor and Recreation Use	Visitor Use	Visitor Use	•	•	•	•	•
Landscapes	Fire and Fuel Dynamics	Fire and Fuel Dynamics	Fire Extent and Severity	•	•	•	•	•
	Landscape Dynamics	Land Cover and Use	Terrestrial Landscape Patterns and Dynamics	†	†	†	†	†

† Vital signs for which ARCN is working independently or jointly with a network park, federal state or private partner to develop and implement monitoring protocol using funding from the vital signs or water quality monitoring programs

• Vital signs that are monitored independently of ARCN by a network park, another NPS program, or another federal, state, or private agency

– Vital Sign will not be monitored in this park

The second tier also includes important vital signs for monitoring in ARCN, focusing on those that must be monitored at broad spatial and temporal scales for effective change detection (Figure 3.2). These vital signs, though critical to understanding change in the arctic parks, would need to be monitored over much longer time frames and at longer intervals (e.g., 10 years). Examples include (1) aerial and volumetric loss of coastal ecosystems in ARCN, monitored by acquisition and analysis of remotely sensed data; (2) landscape and regional-scale changes in terrestrial vegetation, such as latitudinal and elevational shifts in treeline; and (3) changes in fish distributions across the parks (Table 3.3). ARCN has recently acquired baseline data for these vital signs, and protocols should be written for them so effective replication will be possible.

The third group of ecosystem components were vital signs that the technical advisory committee felt were

- sensitive ecological indicators of change,
- relevant at various spatial and temporal scales,
- important for sound management,
- had strong linkages with other vital signs, and
- were not already being monitored.

There are 14 vital signs in this category: Climate and Weather, Snow and Ice, Air Quality, Wet and Dry Deposition of Pollutants, Terrestrial Vegetation and Soils, Lake Communities and Ecosystems, Coastal Lagoons, Stream Communities and Ecosystems, Bird Assemblages, Surface Water Dynamics and Distribution, Permafrost and Thermokarsting, Brown Bears, Small Mammal Assemblages, and Dall's Sheep. During this and previous meetings, each of these vital signs was discussed and reaffirmed. (Please Note: As mentioned in Chapter 1 and diagramed in Table 3.3, water quality parameters are completely integrated with the following three aquatic vital signs: Stream Communites and Ecosystems, Lake Communities and Ecosystems and Lagoon Communites and Ecosystems.)

Several vital signs that emerged from the scoping workshops were not recommended by the Technical Advisory Committee, either because of redundancy with other vital signs or because they were not strong candidates using the above ranking criteria (Table 3.2). Vital signs that were included in this list but that did not make the final list were Shrub Communities/Ecosystems, Wetland Communities/Ecosystems, Riparian Communities/Ecosystems, Point Source Human Effects, Terrestrial Invertebrates, Forest/Woodland Communities, Wolves, Wolverines, Lynx, Furbearers, Beavers, Marmots, and Arctic Ground Squirrels.

Also, as a consequence of the Arctic Network's lack of staff expertise in certain subjects, the development of particular vital signs will be an ongoing process. For example, because ARCN does not have a physical scientist or bird biologist on staff and two of our top vital signs are Weather and Climate and Bird Assemblages, ARCN will be hosting two subject-specific workshops in early FY 2007.

The vital signs lists, framework, overarching conceptual model, and descriptions of each of the vital signs were provided to each member of the board of directors for final approval. In addition to individual meetings with each of the members of the board of directors, the board met to discuss any lingering concerns with the final list of vital signs. All members of the ARCN board of directors expressed satisfaction with the outcome of the vital signs selection and prioritizing process. Questions during this final meeting centered on network staffing and the challenges and costs of monitoring in these most remote parks.

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Glossary of Terms

Adaptive Management: A systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form—"active" adaptive management—employs management programs that are designed to experimentally compare selected policies or practices, by implementing management actions explicitly designed to generate information useful for evaluating alternative hypotheses about the system being managed.

Attribute: Any living or nonliving feature or process of the environment that can be measured or estimated and that provides insights into the state of the ecosystem.

Conceptual ecosystem models: Visual representation of ecosystem components and processes and the interactions and feedbacks between them.

Conceptual "stressor" models: Visual representation of known stressors that may cause changes in park resources.

Ecological integrity: A concept that expresses the degree to which the physical, chemical, and biological components (including composition, structure, and process) of an ecosystem and their relationships are present, functioning, and capable of self-renewal. Ecological integrity implies the presence of appropriate species, populations, and communities and the occurrence of ecological processes at appropriate rates and scales as well as the environmental conditions that support these taxa and processes.

Ecosystem: "A spatially explicit unit of the Earth that includes all of the organisms, along with all components of the abiotic environment within its boundaries" (Likens 1992).

Ecosystem attributes (vital signs): Component or process of an ecosystem used to determine the long-term "health" of an ecosystem.

Ecosystem components: Part(s) of an ecosystem (e.g., nitrogen, eelgrass, insect, seal, water).

Ecosystem drivers: Major external driving forces such as climate, fire cycles, biological invasions, hydrologic cycles, and natural disturbance events (e.g., earthquakes, droughts, floods) that have large-scale influences on natural systems.

Ecosystem function: All physical and chemical properties of a structure that relate to its form and organization, excluding the action or use of the structure that is more critically termed its role (e.g., dispersal mechanism, ecosystem stability).

Ecosystem management: The process of land-use decision-making and land-management practice that takes into account the full suite of organisms and processes that characterize and comprise the ecosystem. It is based on the best understanding currently available of how the ecosystem works. Ecosystem management includes a primary goal to sustain ecosystem structure and function, a recognition that ecosystems are spatially and temporally dynamic, and acceptance of the dictum that ecosystem function depends on ecosystem structure and diversity. The whole-system focus of ecosystem management implies coordinated land-use decisions.

Ecosystem process: A series of ecosystem actions or changes bringing about a result (e.g., decomposition, photosynthesis).

Ecotone: The boundary or transitional zone between adjacent communities or biomes (e.g., riparian zone).

Focal resources: Park resources that, by virtue of their special protection, public appeal, or other management significance, have paramount importance for monitoring regardless of current threats or whether they would be monitored as an indication of ecosystem integrity. Focal resources might include ecological processes such as deposition rates of nitrates and sulfates in certain parks, or they may be a species that is harvested, endemic, alien, or has protected status.

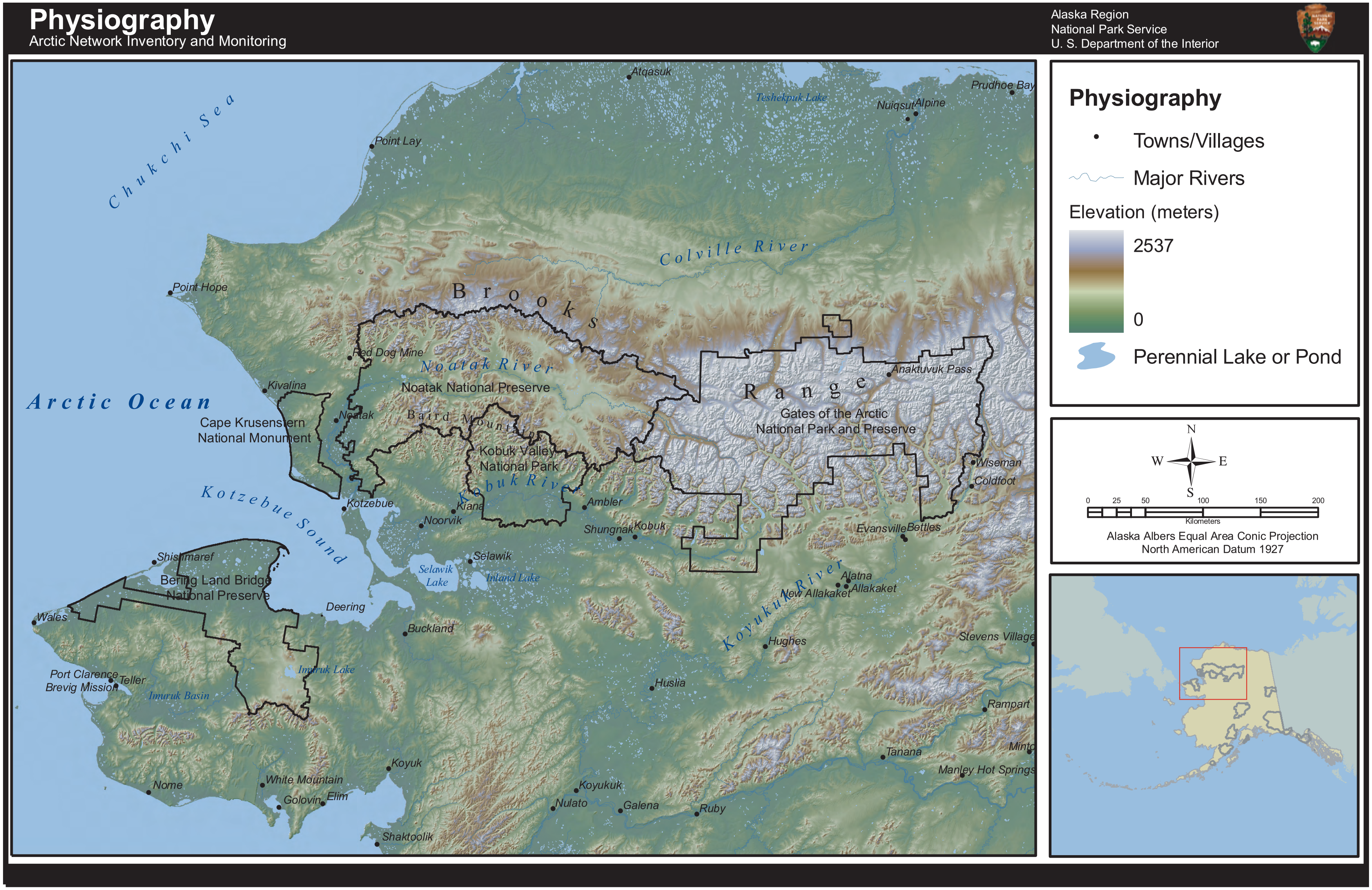
Indicators: A subset of monitoring attributes that are particularly information-rich in the sense that their values are somehow indicative of the quality, health, or integrity of the larger ecological system to which they belong (Noon 2003). Indicators are a selected subset of the physical, chemical, and biological elements and processes of natural systems that are selected to represent the overall health or condition of the system.

Measures: The specific feature(s) used to quantify an indicator, as specified in a sampling protocol.

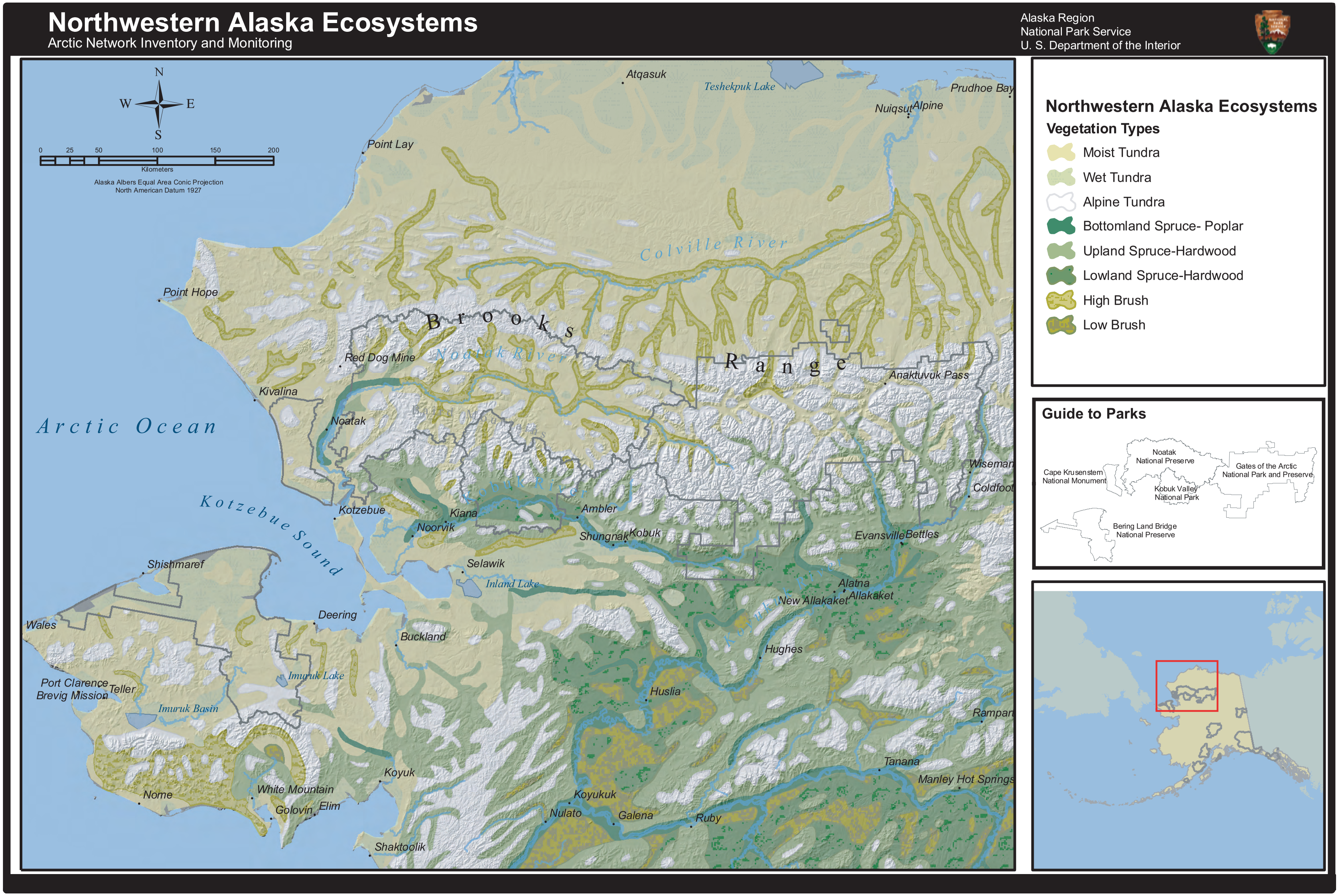
Stressors: Physical, chemical, or biological perturbations to a system that are either (a) foreign to that system or (b) natural to the system but applied at an excessive (or deficient) level (Barrett et al. 1976:192). Stressors cause significant changes in the ecological components, patterns, and processes in natural systems. Examples include water withdrawal, pesticide use, timber harvesting, traffic emissions, stream acidification, trampling, poaching, land-use change, and air pollution.

Vital Signs: As used by the National Park Service, a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. The elements and processes that are monitored are a subset of the total suite of natural resources that park managers are directed to preserve "unimpaired for future generations," including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources. Vital signs may occur at any level of organization including landscape, community, population, or genetic level, and may be compositional (referring to the variety of elements in the system), structural (referring to the organization or pattern of the system), or functional (referring to ecological processes).

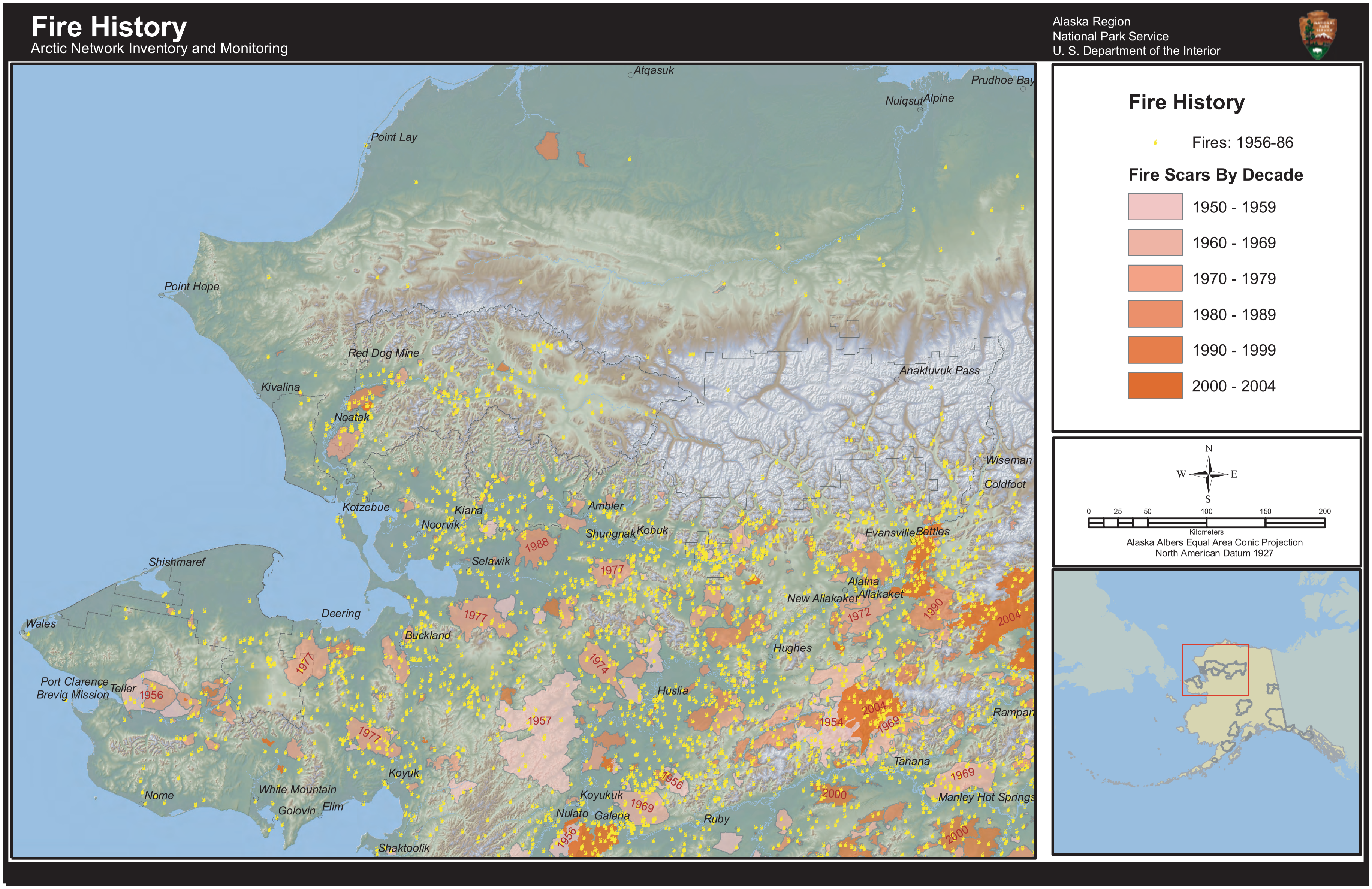
Network Maps



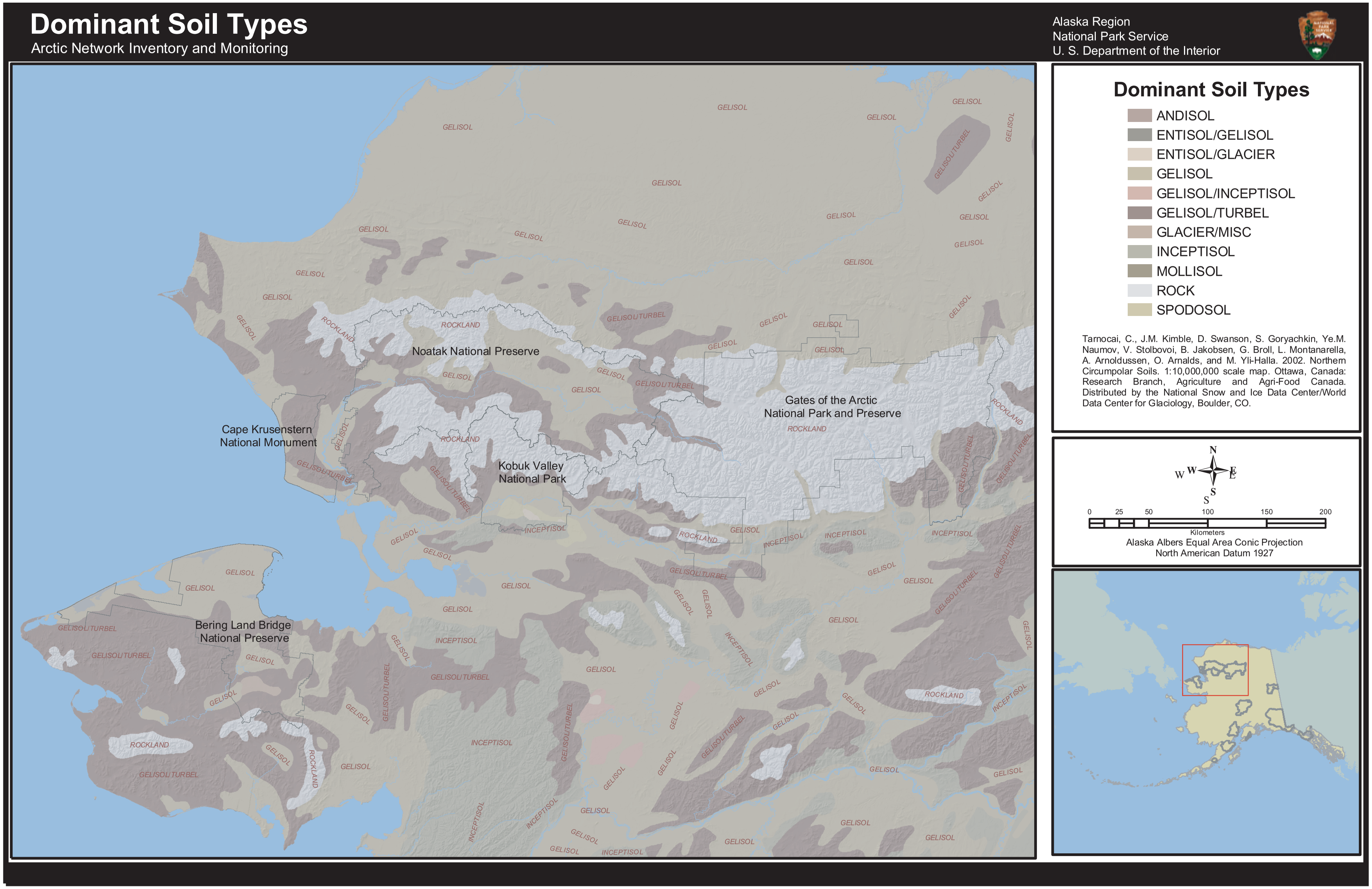
Map 1. *Physiography of ARCN. Digital elevation model 90 m grid for Alaska, from best available data. In some areas of missing data, a 300 m and 60 m DEM were used to patch in.*



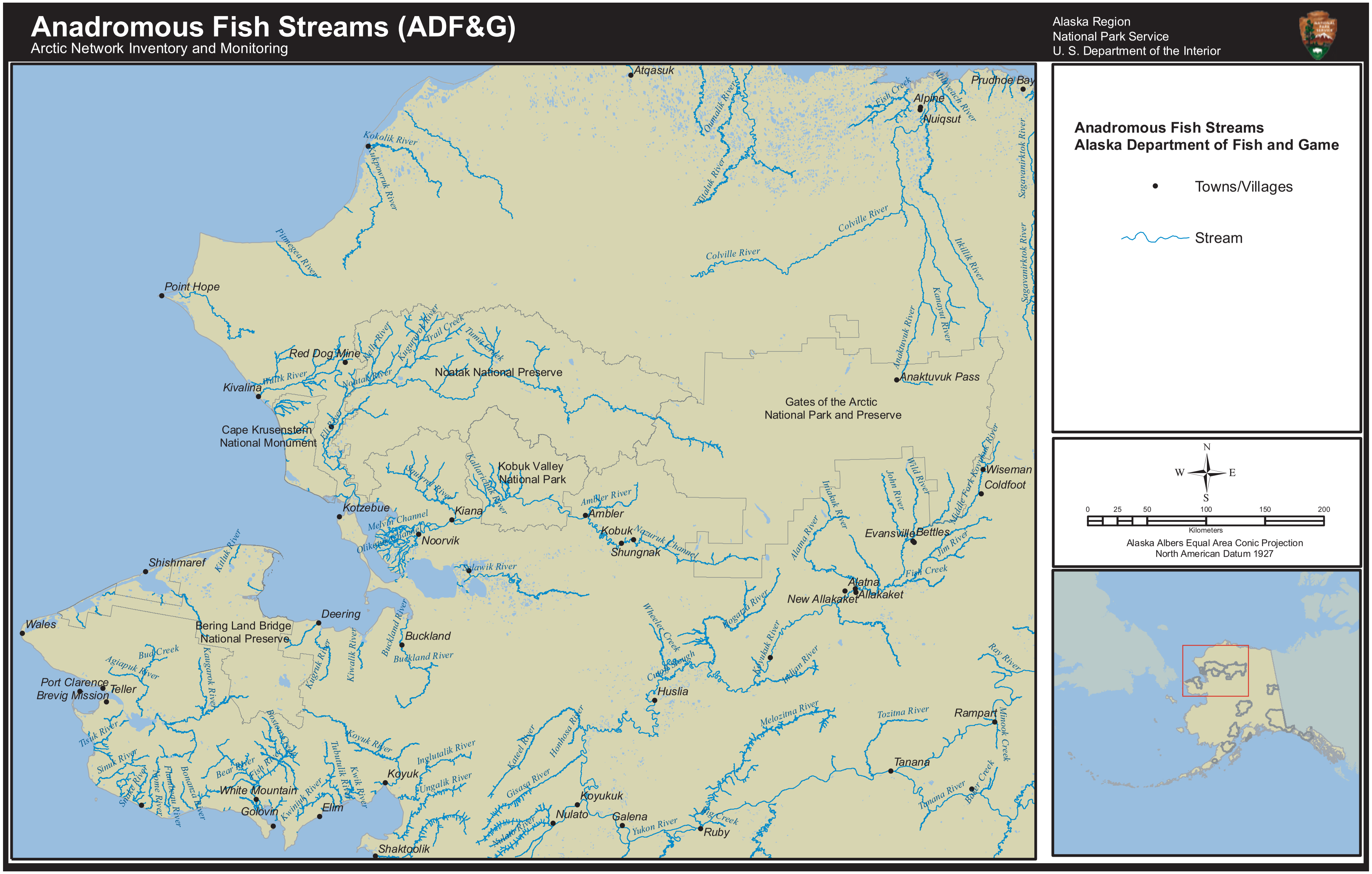
Map 2. *The 1973 map of "Major Ecosystems of Alaska" shows the distribution of nine classes of ecosystems within a single hierarchic level. Scale of coverage is 1:250:000. The focus of the ecosystems map is on the regional distribution of vegetation community type and structure. Information relating to other landscape characteristics, such as topography, hydrology, and climate, is considered only so far as it influences ecosystem type. (NPS Alaska Region Support Office.)*



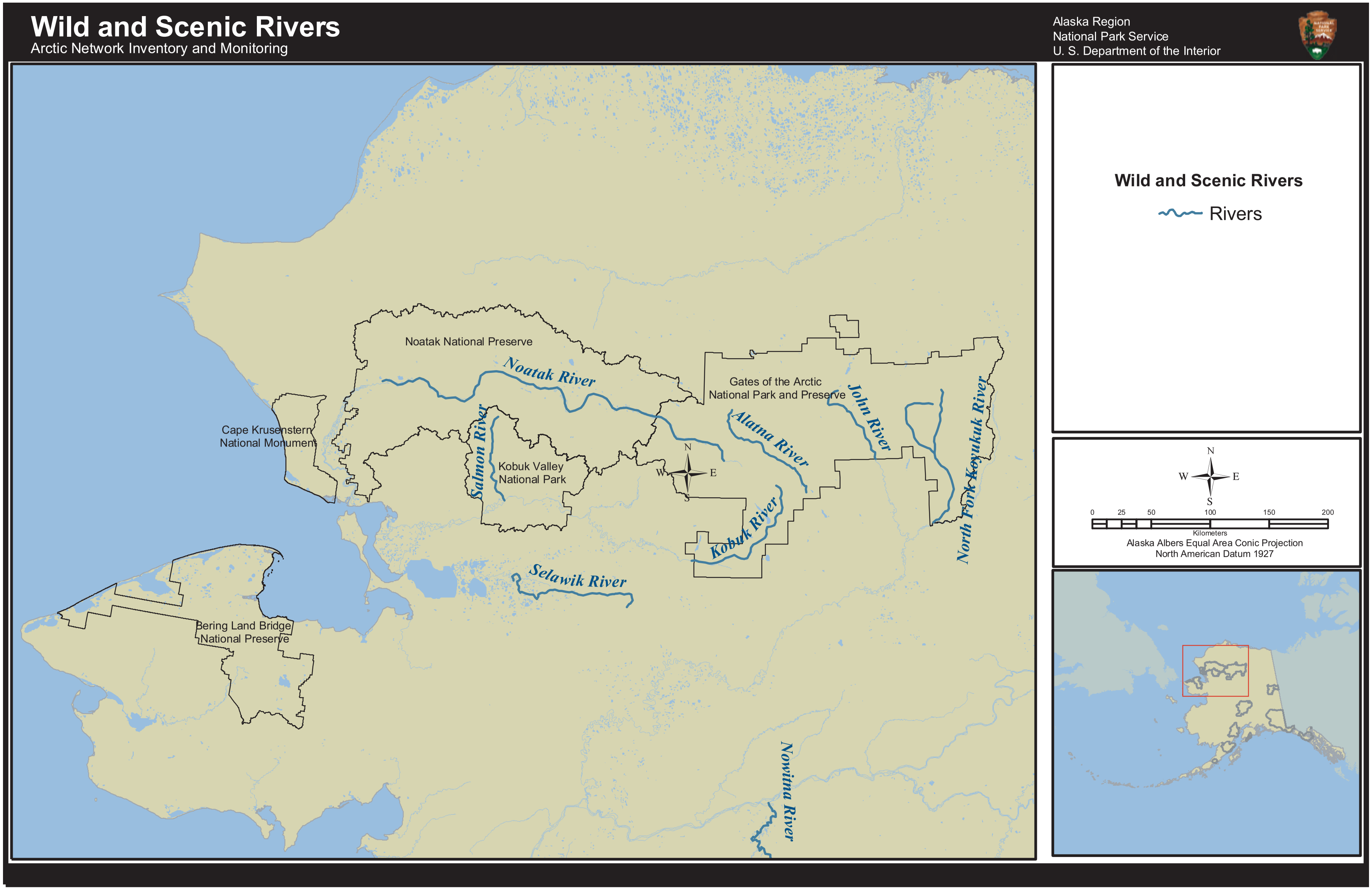
Map 3. Fire history of northwest Alaska. Point data shows historic fire ignitions, 1950 to 2004. Area polygons represent historical wildland fire perimeters of fires greater than 1,000 acres between 1950 and 1987, inclusive, and fires greater than 100 acres between 1988 and 2002, inclusive. Data were compiled from BLM Alaska Fire Service, State of Alaska Department of Forestry and National Park Service records. (NPS Alaska Regional Office, BLM Alaska Fire Service, Environmental Resource Institute of Michigan.)



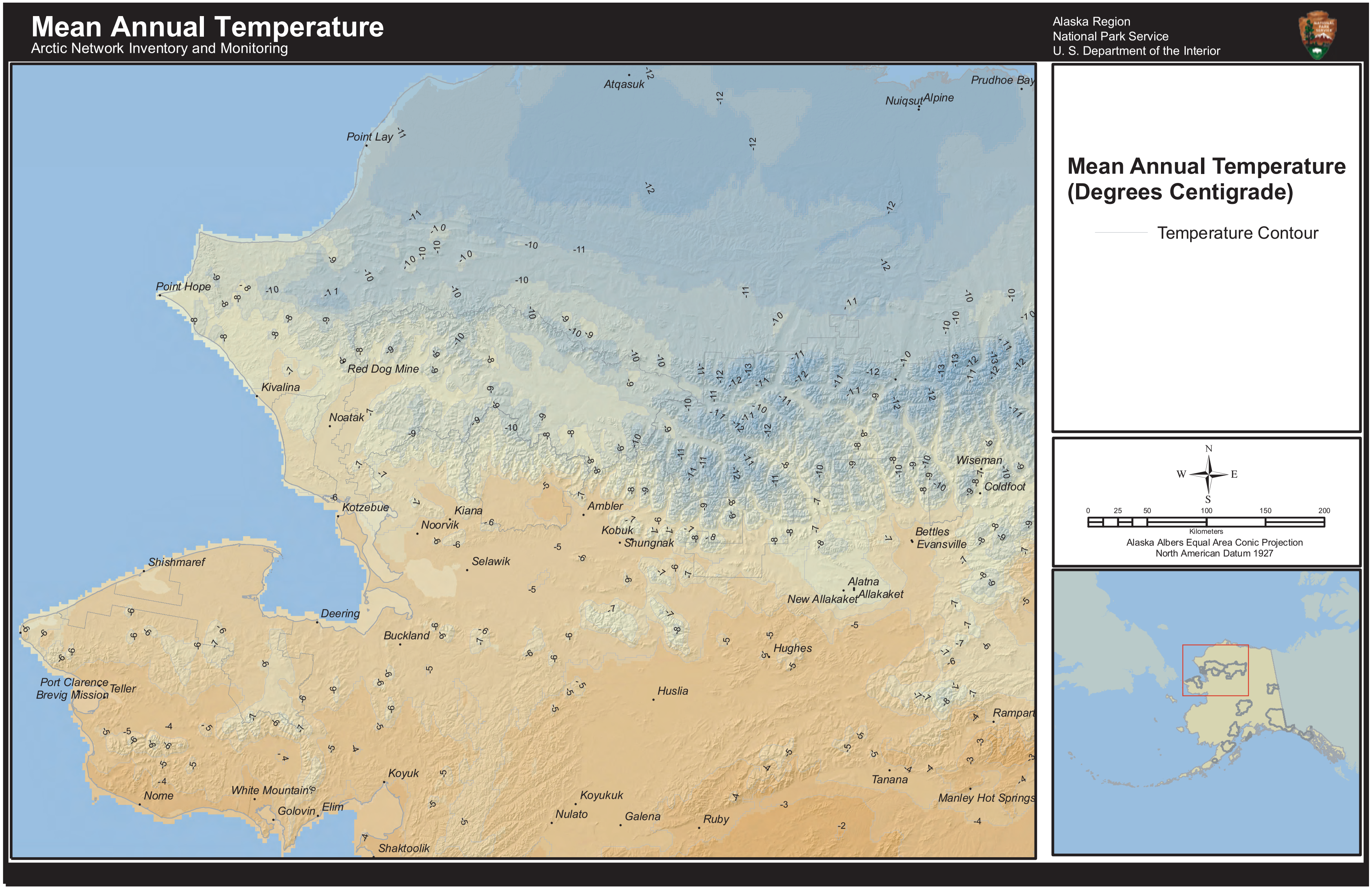
Map 4. *Map of northwestern Alaskan dominant soil characteristics. The map was created using the Northern and Mid Latitude Soil Database. The map shows the dominant soil of each spatial polygon unless the polygon is over 90 percent rock or ice. Soils include turbels, orthels, histels, mollisols, vertisols, aridsols, andisols, entisols, spodosols, incpetisols (and hapludolls), alfisols (cryalf and udalf), natric great groups, aqu-suborders, glaciers, and rocklands.*



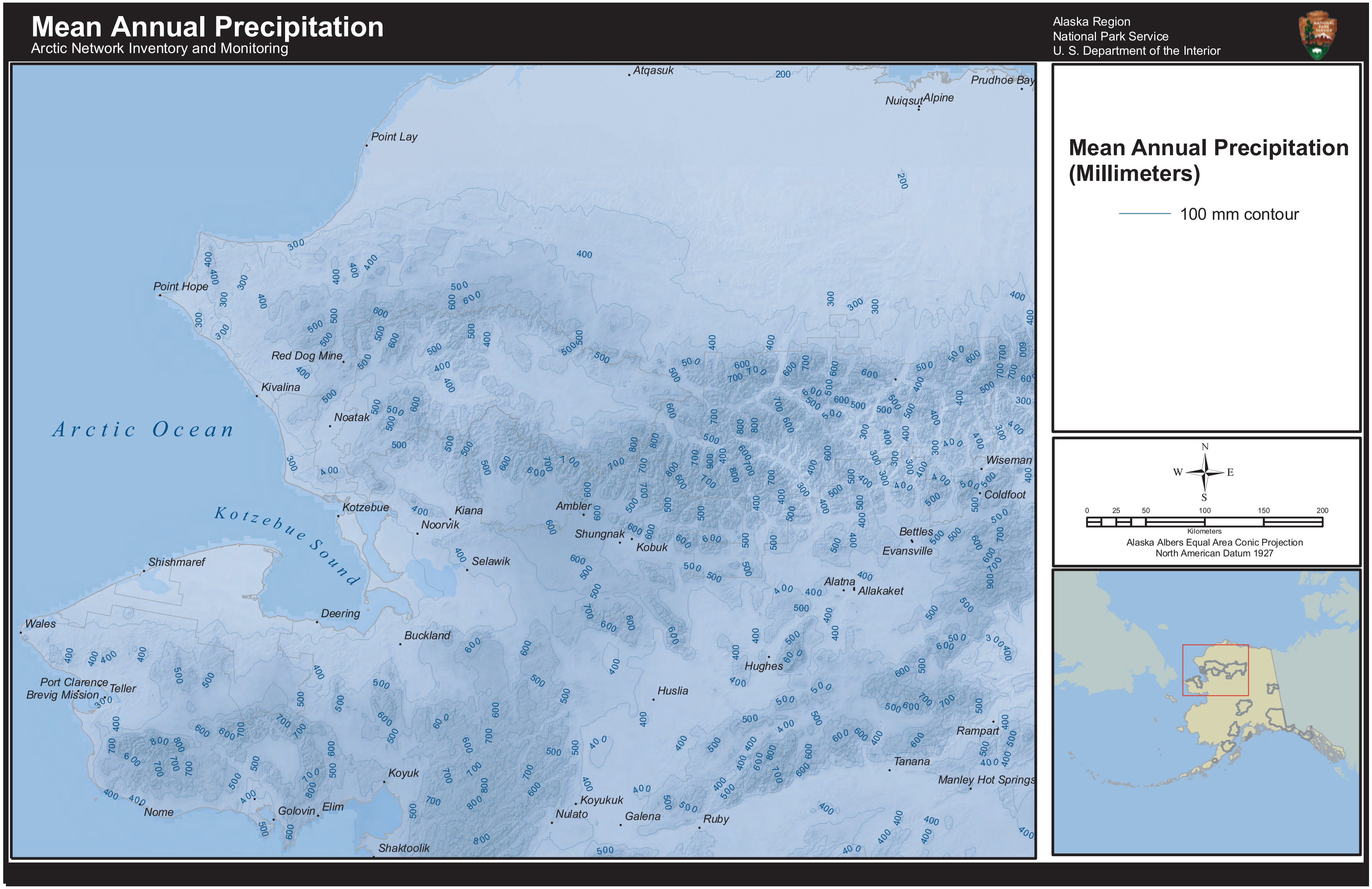
Map 5. Anadromous fish streams. The Alaska Department of Fish and Game's (ADF&G) Anadromous Streams data is derived from the ADF&G's "Catalog of Waters Important for Spawning, Rearing, or Migration of Anadromous Fishes" and the "Atlas to the Catalog of Waters Important for Spawning, Rearing, or Migration of Anadromous Fishes." The map depicts the known anadromous fish bearing streams within Alaska (from the mouth to the known upper extent of species usage). It incorporates data from a variety of sources, including USGS Digital Line Graph (DLG) and National Hydrography Dataset (NHD) hydrography data; Alaska Department of Natural Resources hydrography layer; and ADF&G data for the atlas and catalog. Data for the shapefiles are current as of January 15, 2005.



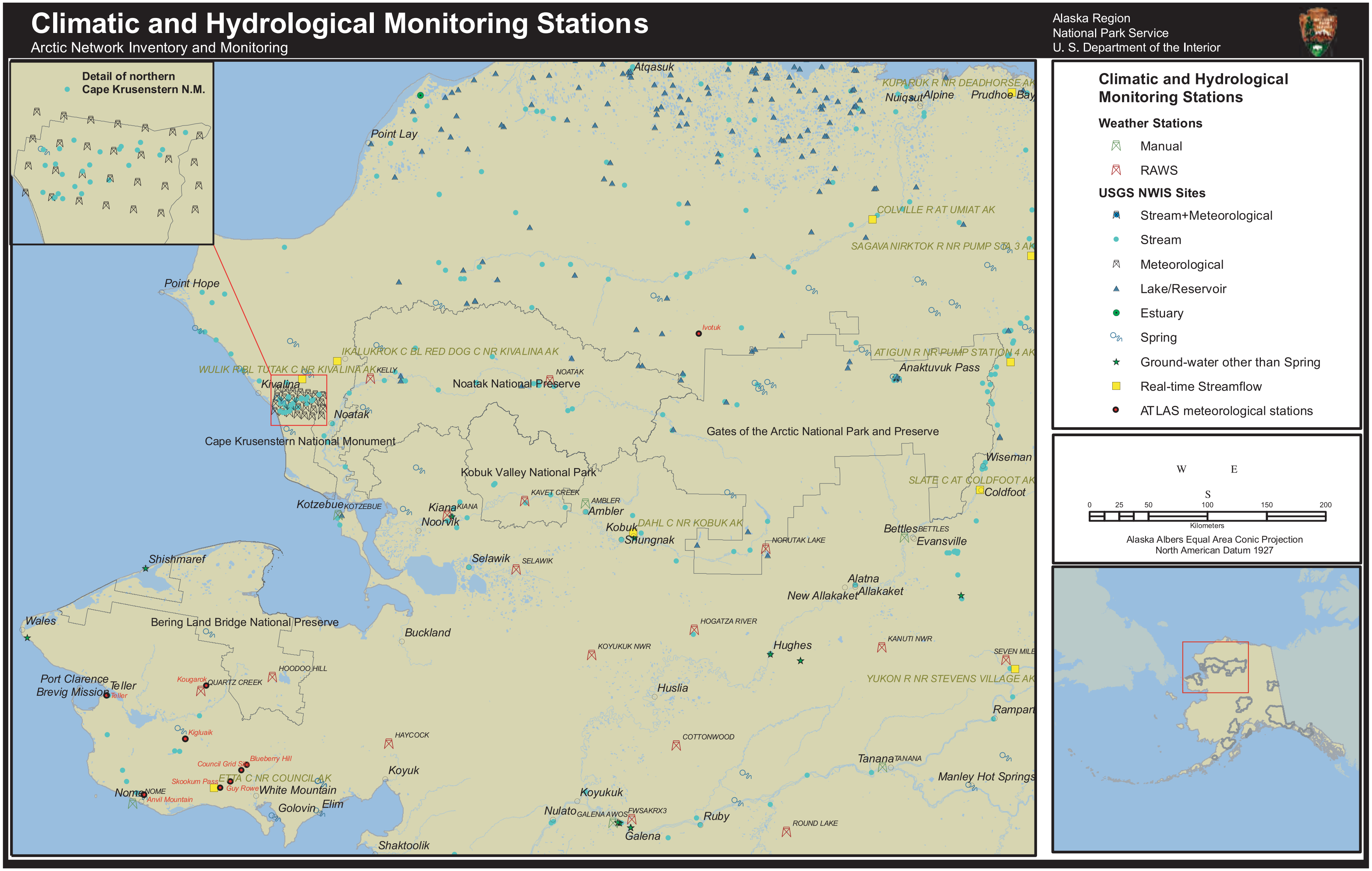
Map 6. Wild and scenic rivers in ARCN.



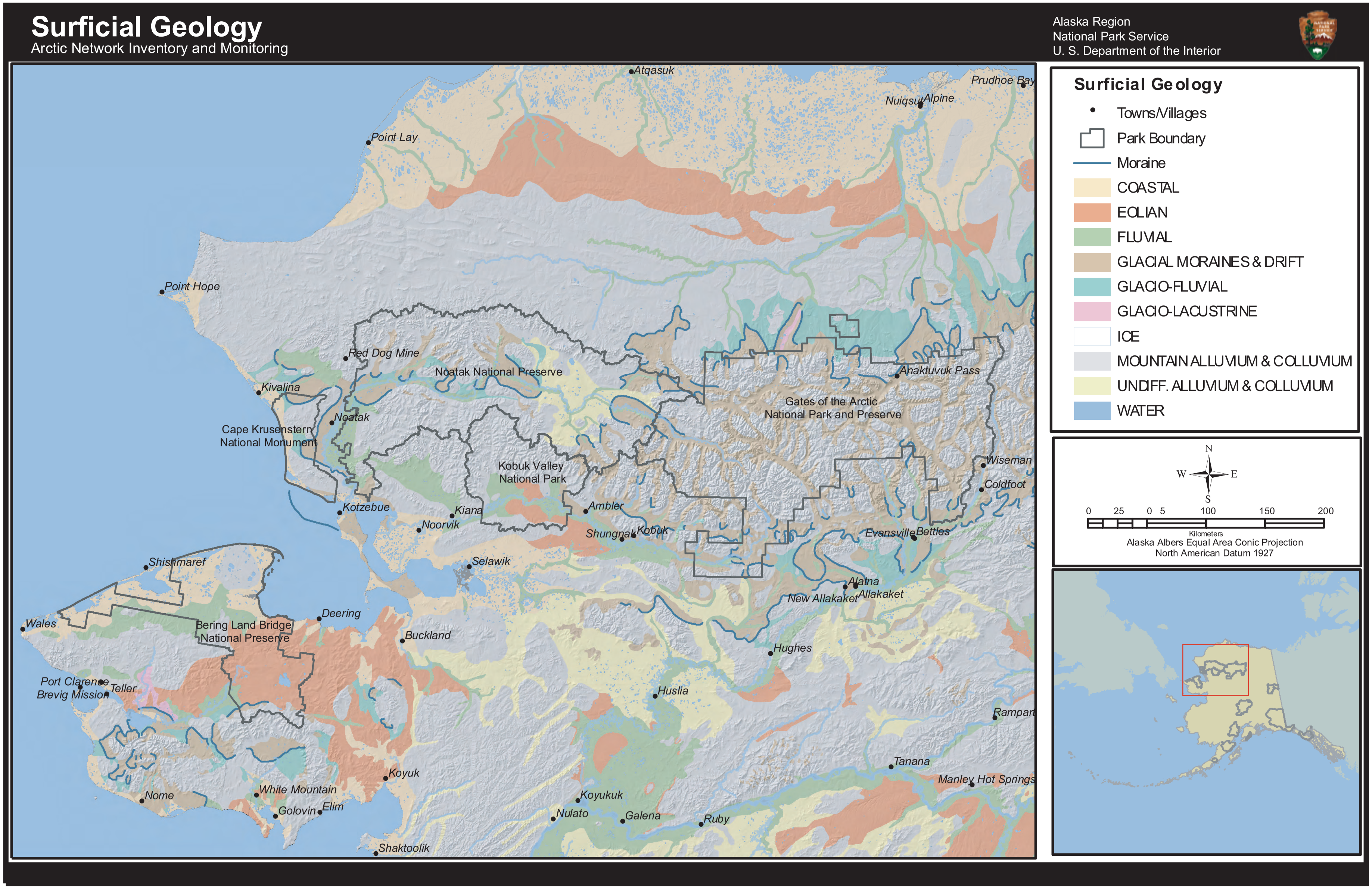
Map 7. *This map contains spatially gridded average monthly and annual mean temperature for the climatological period 1961–1990 for Alaska. Distribution of the point measurements to a spatial grid was accomplished using the PRISM model, developed by Christopher Daly of SCAS/OSU.*



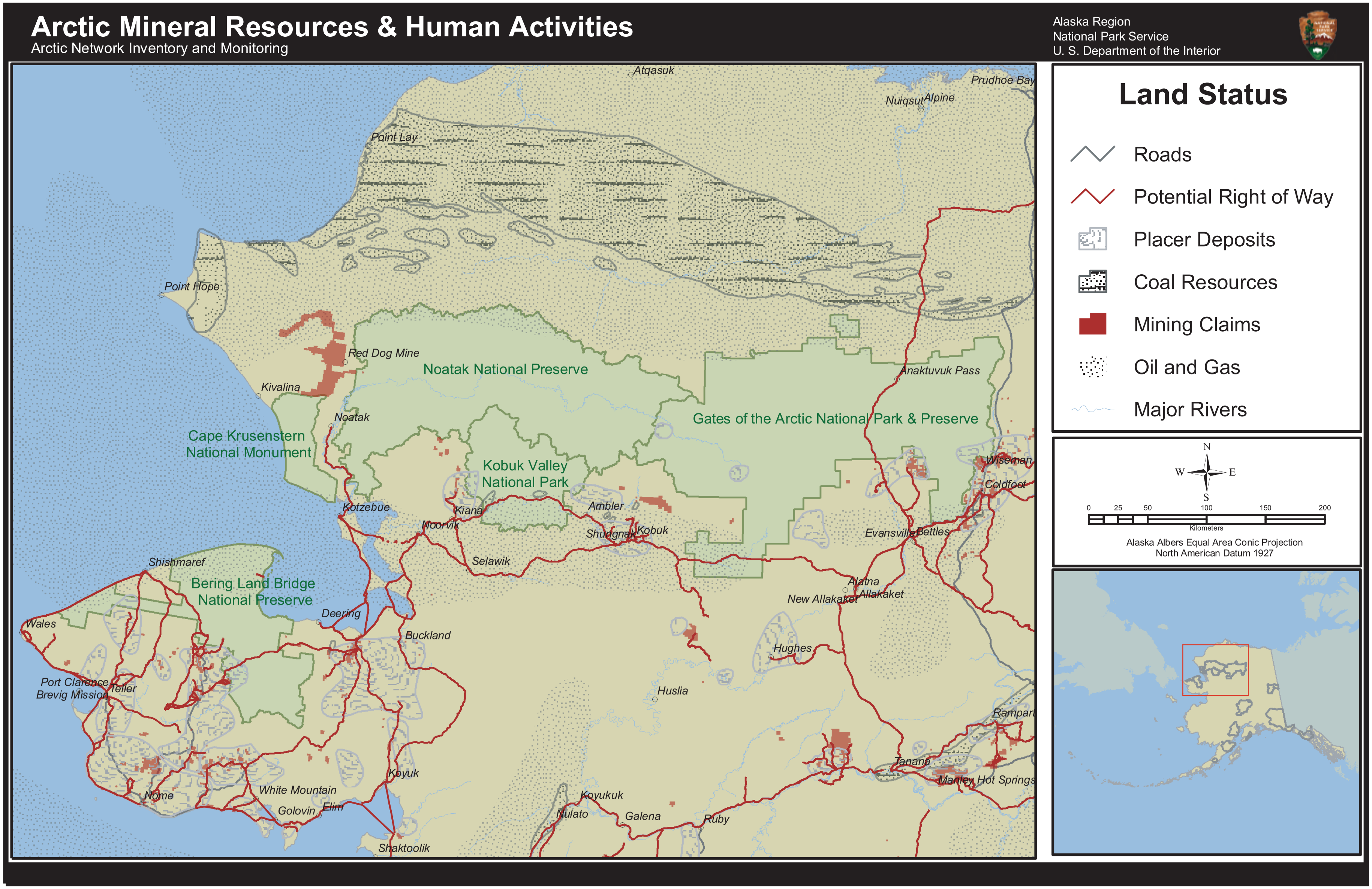
Map 8. This map contains spatially gridded average monthly and annual precipitation for the climatological period 1961–1990 for Alaska. Distribution of the point measurements to a spatial grid was accomplished using the PRISM model, developed by Christopher Daly of SCAS/OSU.



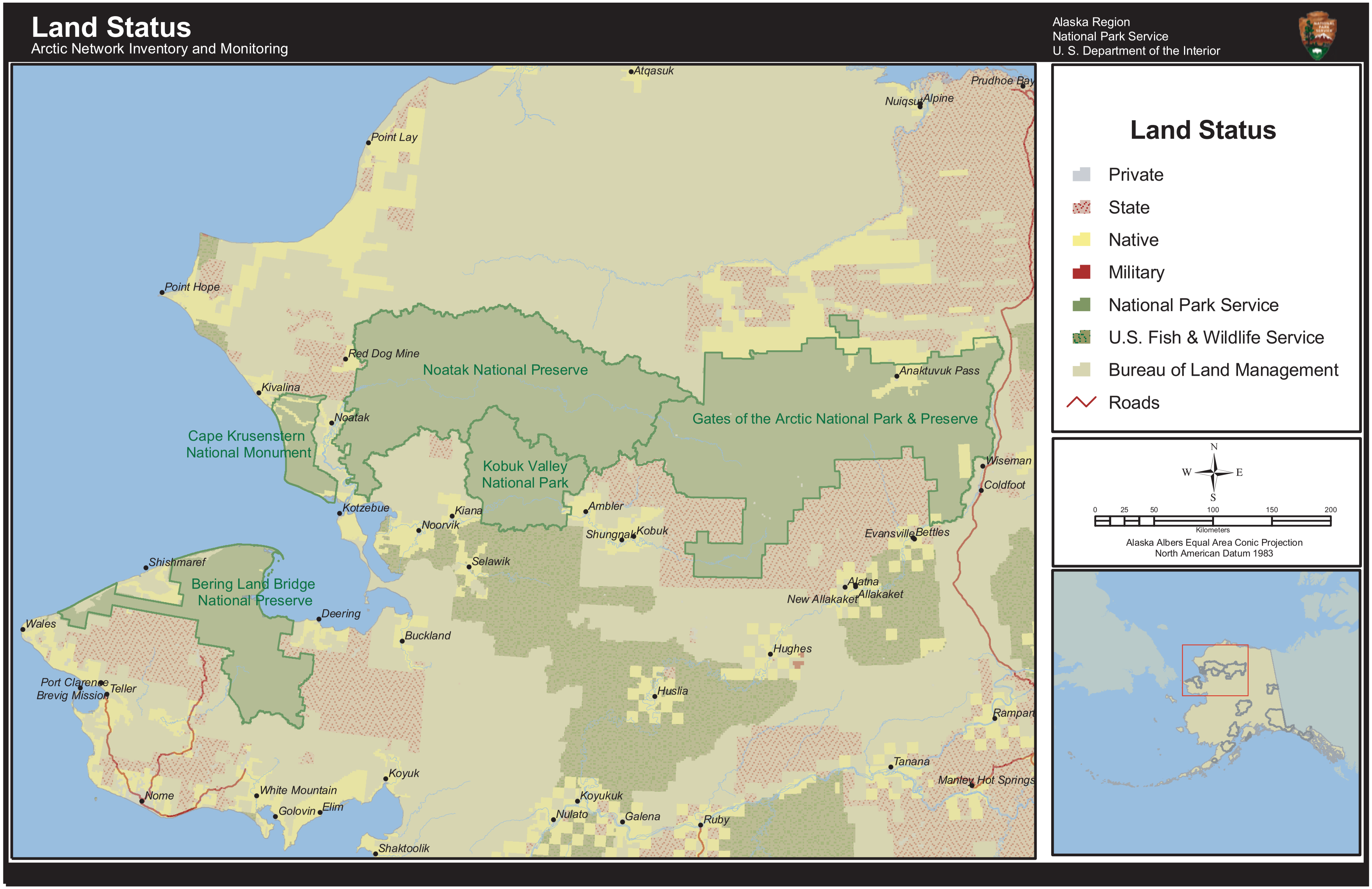
Map 9. Remote automated weather stations (RAWS) and manual weather stations throughout Alaska. USGD data obtained from the NWIS database. Most sites consist of one-time water quality sampling events. Stream discharge is not measureed within any arctic park, but there is real-time data collected downstream of the parks at five locations. Arctic Transitions in the Land-Atmosphere System (ATLAS) meteorological stations on the Seward Peninsula from University of Alaska Fairbanks Water and Environmental Research Center website.



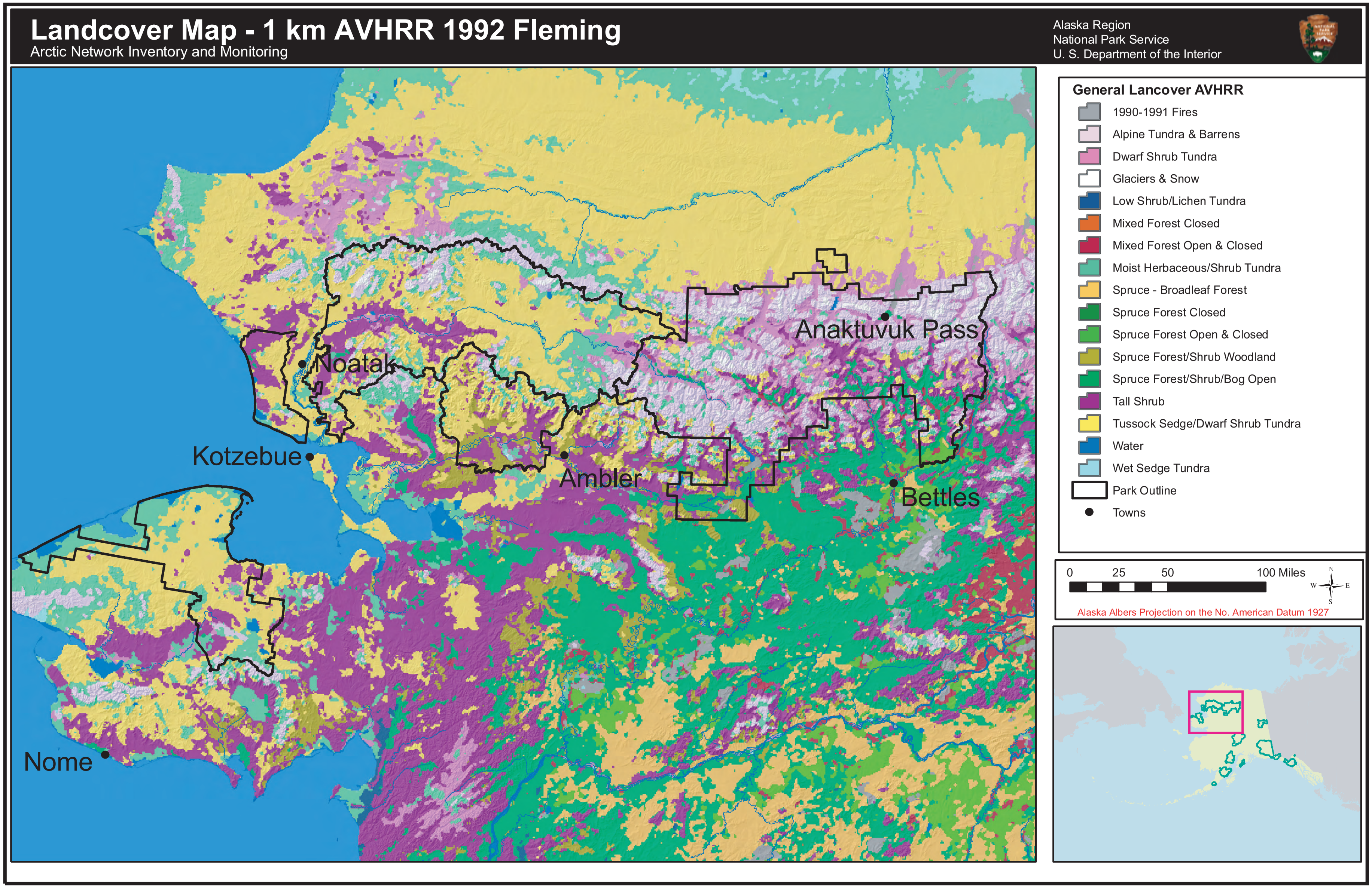
***Map 10**. Surficial geology. Data from digital version of two USGS maps titled Miscellaneous Geologic Investigations (West) I-357 and Miscellaneous Geologic Investigations (East) I-357 in association with the work of Karlstrom et al. 1964.*



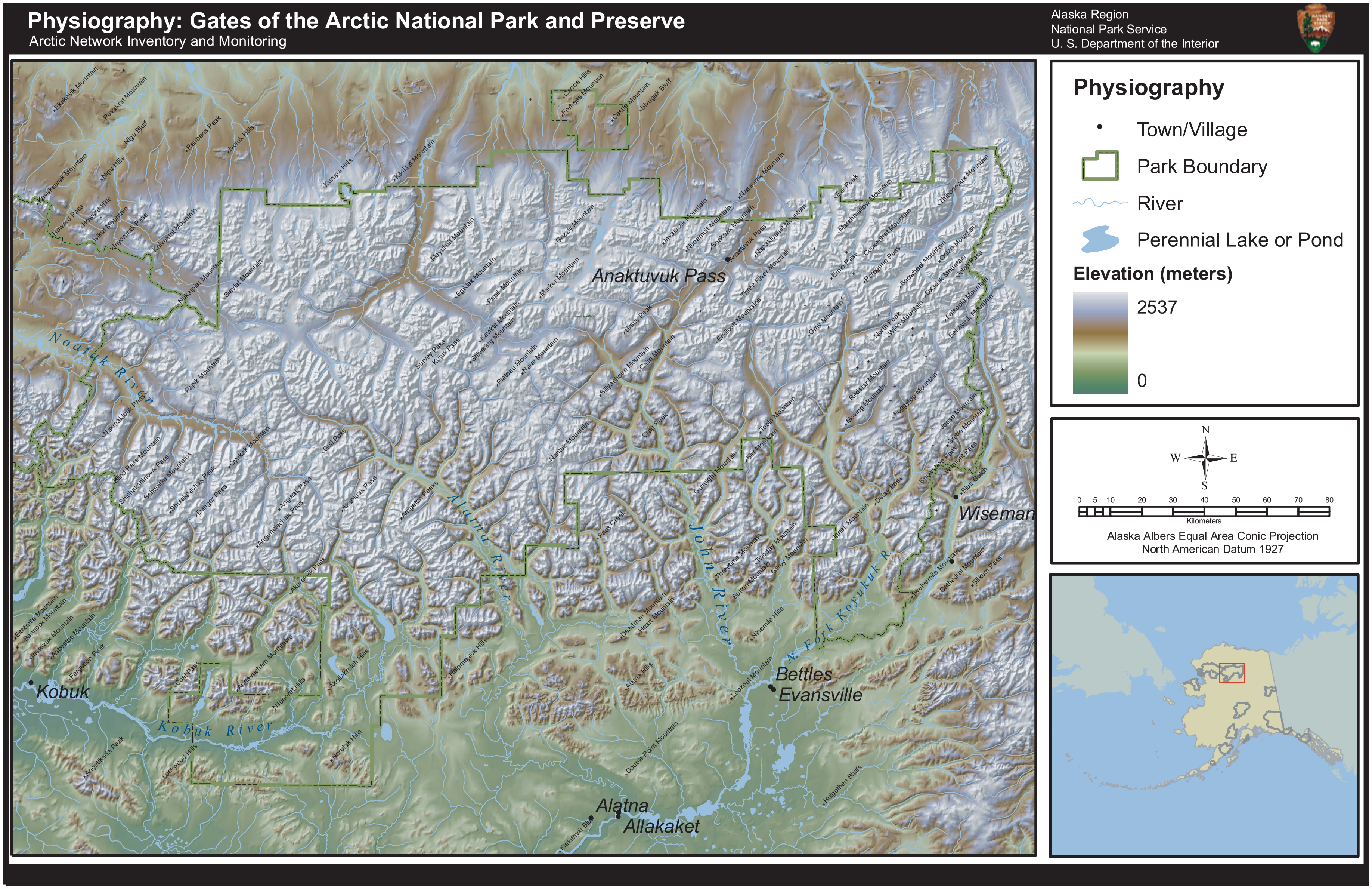
Map 11. Arctic mineral resources, mining claims, and oil and gas basins. Current BLM case type, case status, and land status information was used to classify data extracted from federal land records stored in the Alaska Land Information System (ALIS). Data also from the Alaska Department of Natural Resources, Land Records Information and Division of Geological and Geophysical Surveys. Potential rights-of-way (ROW) established under the federal Revised Statute 2477 from Department of Natural Resources Land Administration System (LAS).



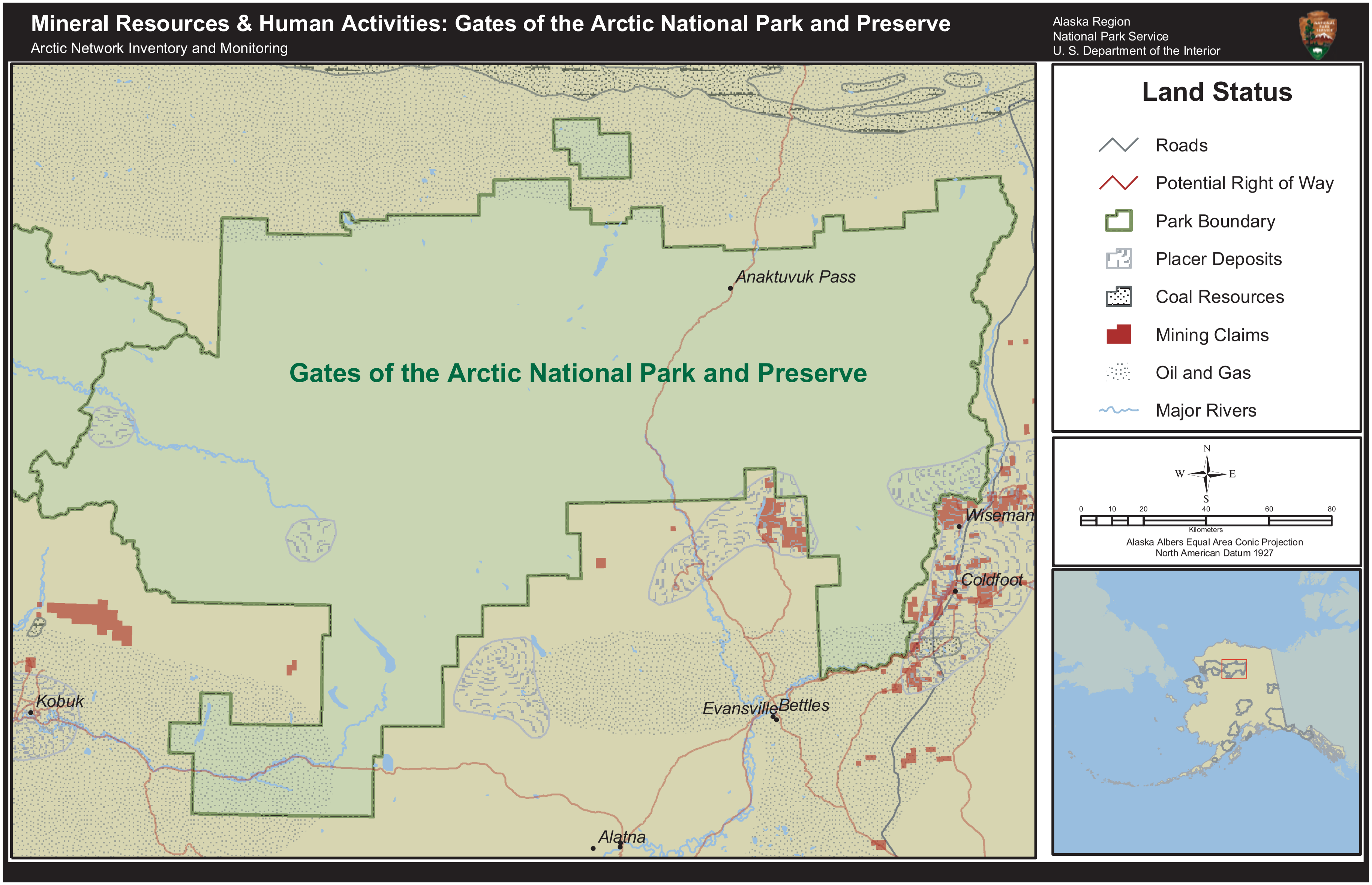
Map 12. Land ownership at the section level for the state of Alaska. Land ownership and status records used to create this map were extracted from two major sources: Bureau of Land Management (BLM) Alaska Land Information System (ALIS) on January 5, 2004; and the State of Alaska Department of Natural Resources (ADNR) Land Administration System (LAS) on April 16, 2004.



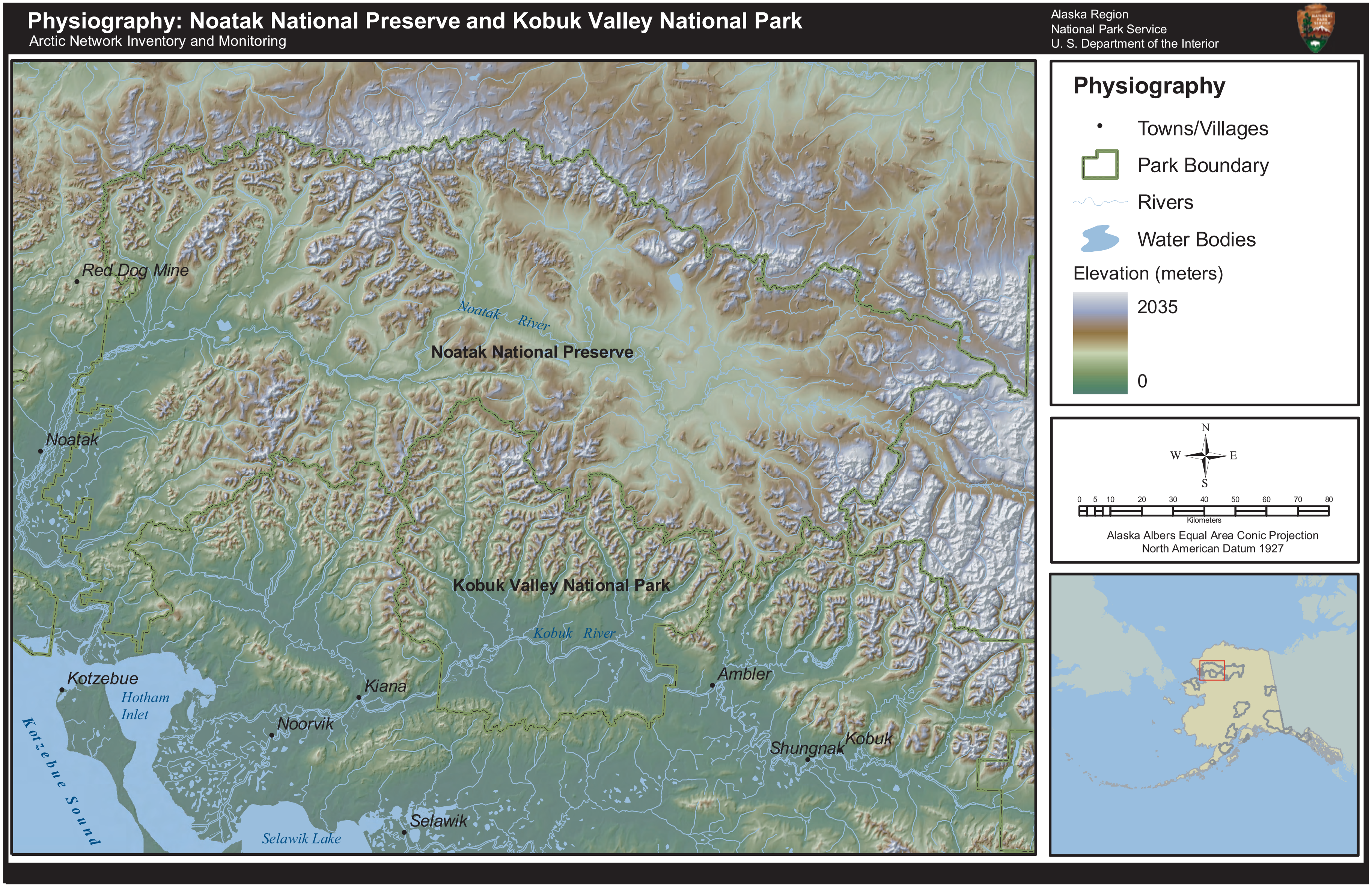
Map 13. Landcover vegetation map of Alaska developed by Michael Fleming of the USGS using AVHRR and NDVI data collected during the 1991 growing season. The original map has 23 classes; some of these classes have been collapsed or renamed for the purpose of display. Scale of the map is 1-km grid size. The GIS coverage for this map is available at <http://agdc.usgs.gov/data/projects/fhm/#G>.



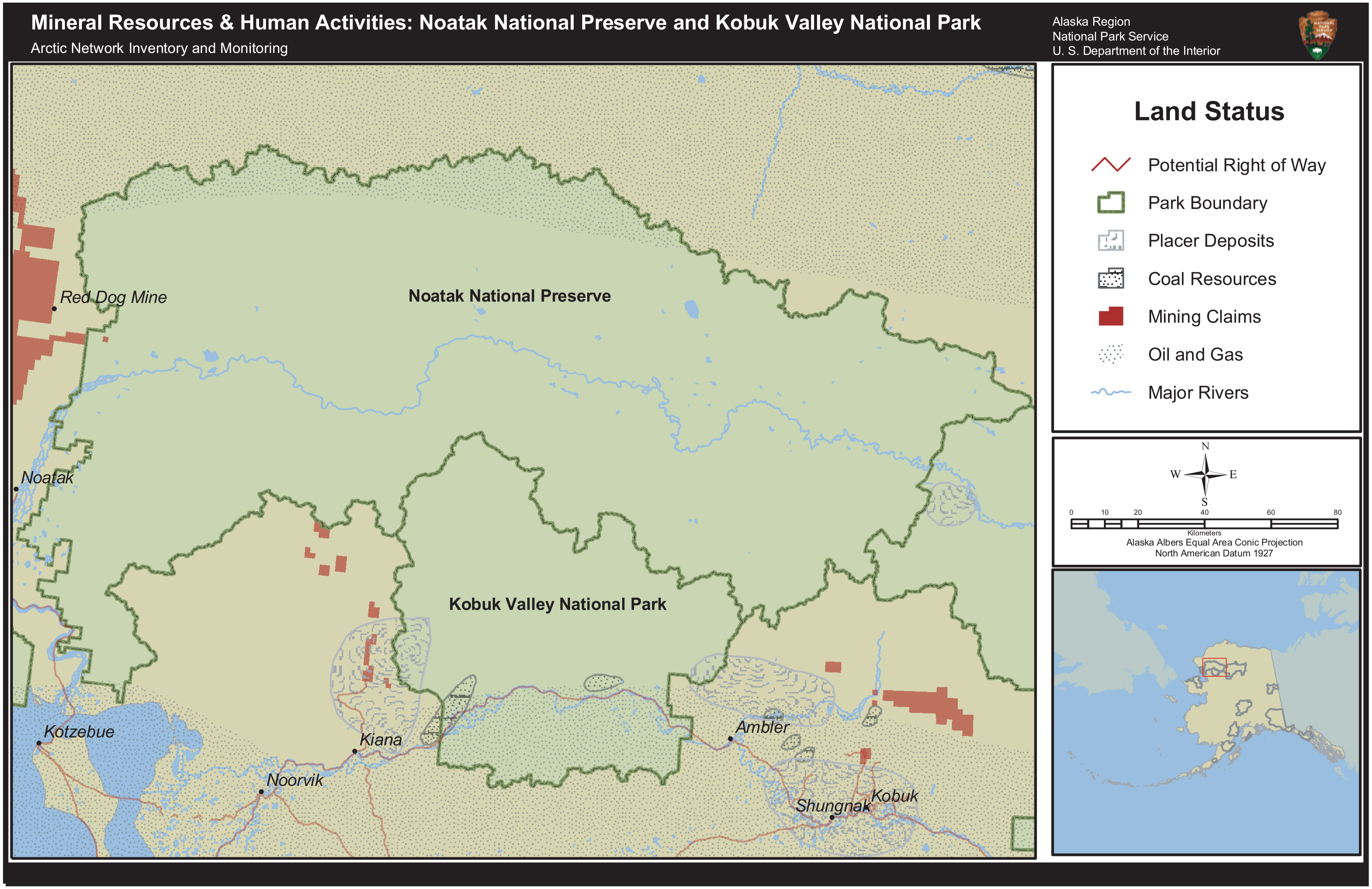
Map 14. Physiography of Gates of the Arctic National Park and Preserve. Digital elevation model 90 m grid for Alaska, from best available data. In some areas of missing data, a 300 m and 60 m DEM were used to patch in.



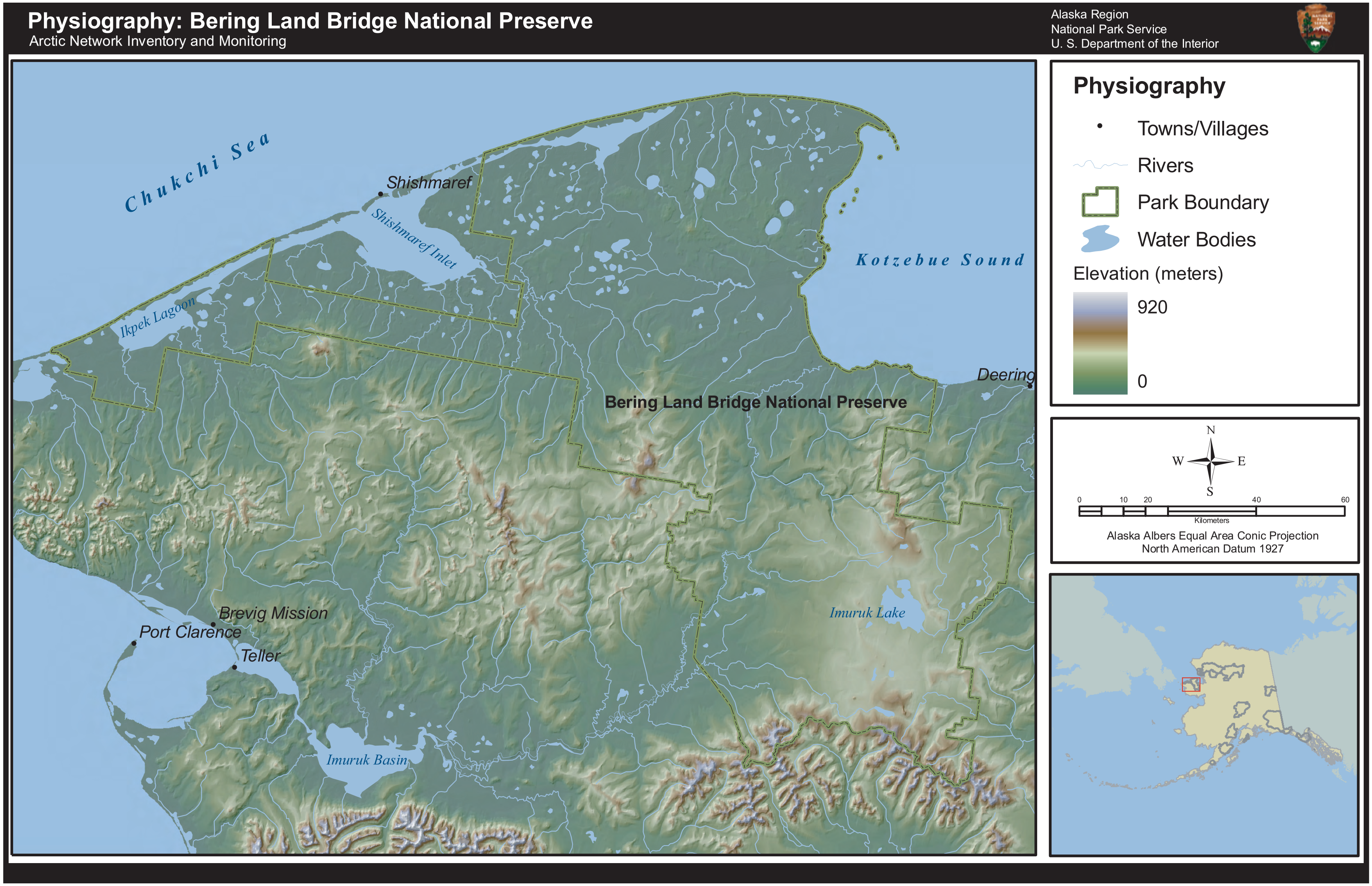
Map 15. Mineral resources, mining claims, and oil and gas basins in Gates of the Arctic National Park and Preserve. Current BLM case type, case status, and land status information was used to classify data extracted from federal land records stored in the Alaska Land Information System (ALIS). Data also from the Alaska Department of Natural Resources, Land Records Information and Division of Geological and Geophysical Surveys. Potential rights-of-way (ROW) established under the federal Revised Statute 2477 from Department of Natural Resources Land Administration System (LAS).



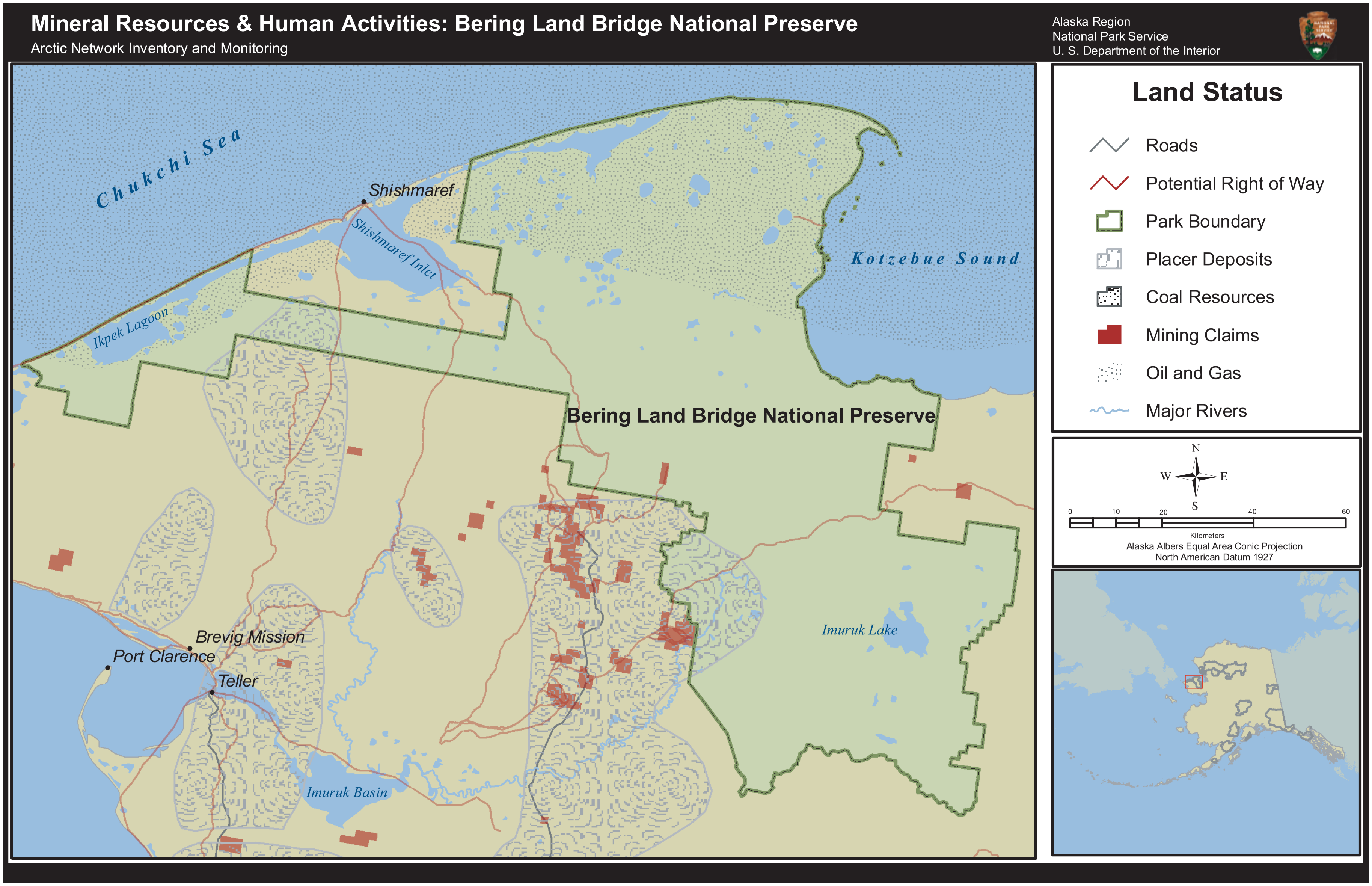
Map 16. *Physiography of Noatak National Preserve and Kobuk Valley National Park. Digital elevation model 90 m grid for Alaska, from best available data. In some areas of missing data, a 300 m and 60 m DEM were used to patch in.*



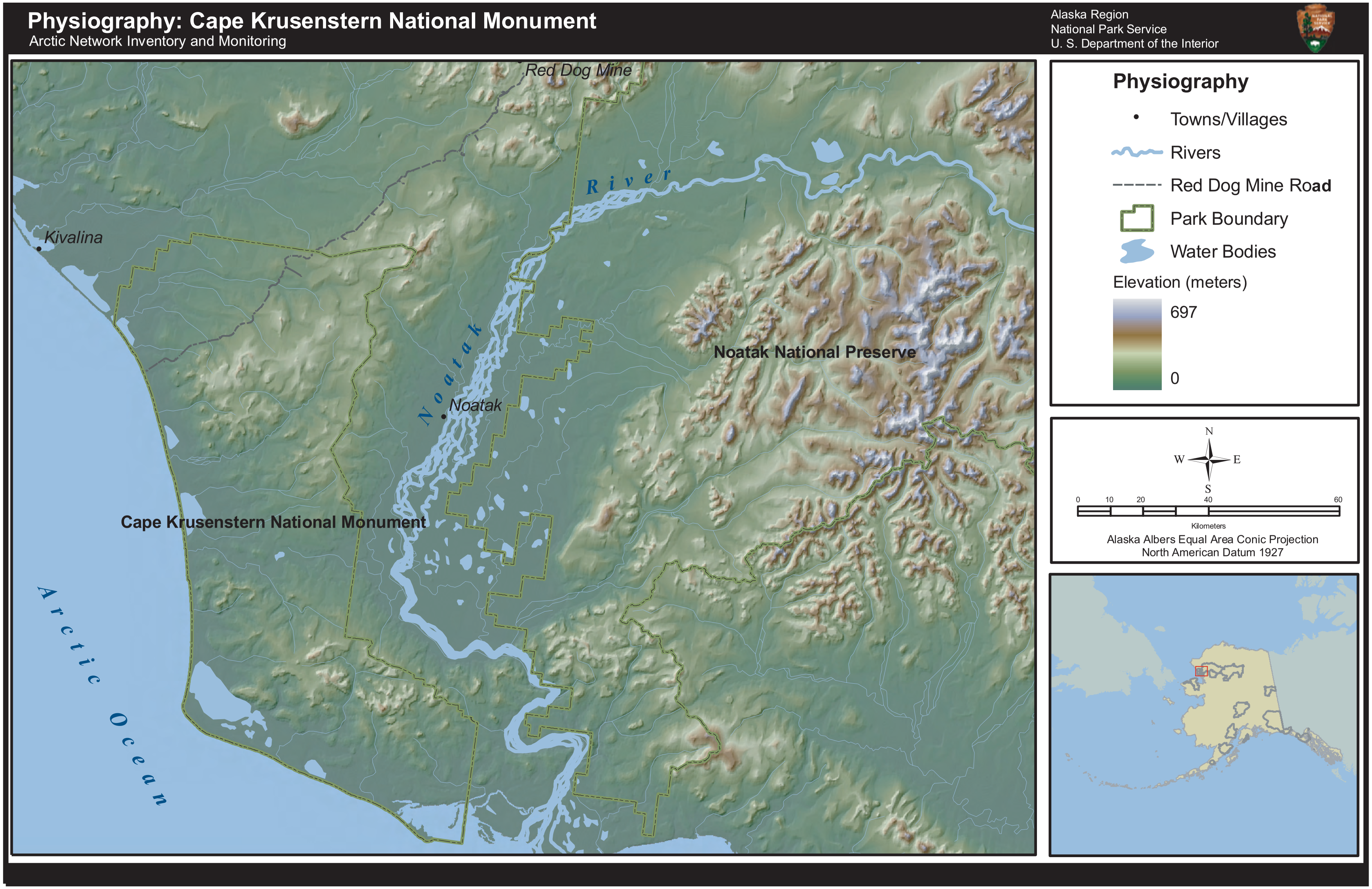
Map 17. *Mineral resources, mining claims, and oil and gas basins in Noatak National Preserve and Kobuk Valley National Park. Current BLM case type, case status, and land status information was used to classify data extracted from federal land records stored in the Alaska Land Information System (ALIS). Data also from the Alaska Department of Natural Resources, Land Records Information and Division of Geological and Geophysical Surveys. Potential rights-of-way (ROW) established under the federal Revised Statute 2477 from Department of Natural Resources Land Administration System (LAS).*



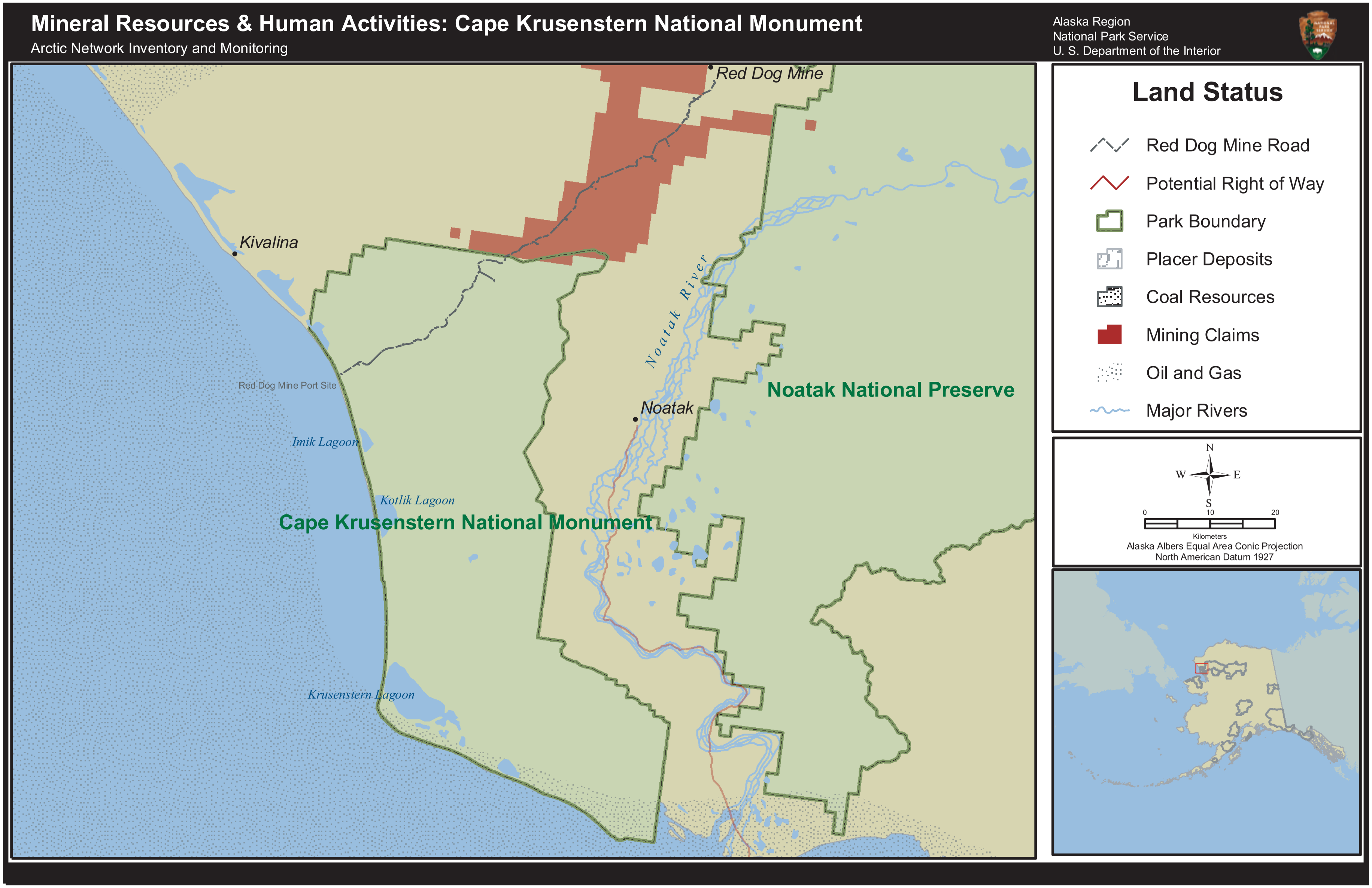
Map 18. *Physiography of Bering Land Bridge National Preserve. Digital elevation model 90 m grid for Alaska, from best available data. In some areas of missing data, a 300 m and 60 m DEM were used to patch in.*



Map 19. *Mineral resources, mining claims, and oil and gas basins in Bering Land Bridge National Preserve. Current BLM case type, case status, and land status information was used to classify data extracted from federal land records stored in the Alaska Land Information System (ALIS). Data also from the Alaska Department of Natural Resources, Land Records Information and Division of Geological and Geophysical Surveys. Potential rights-of-way (ROW) established under the federal Revised Statute 2477 from Department of Natural Resources Land Administration System (LAS).*



Map 20. *Physiography of Cape Krusenstern National Monument. Digital elevation model 90 m grid for Alaska, from best available data. In some areas of missing data, a 300 m and 60 m DEM were used to patch in.*



Map 21. *Mineral resources, mining claims, and oil and gas basins in Cape Krusenstern National Monument. Current BLM case type, case status, and land status information was used to classify data extracted from federal land records stored in the Alaska Land Information System (ALIS). Data also from the Alaska Department of Natural Resources, Land Records Information and Division of Geological and Geophysical Surveys. Potential rights-of-way (ROW) established under the federal Revised Statute 2477 from Department of Natural Resources Land Administration System (LAS).*

Appendix 1
Superintendent Interviews

Introduction

Park superintendents' input to the Arctic Network (ARCN) Monitoring Program is critical to its long-term success. The purpose of this interview is to help us better understand the current and future challenges you face in managing your parklands and how best to make the ARCN monitoring program relevant to parks. The following is a series of questions about the natural resources, threats to those resources, and major resource management issues facing the parks now and in the foreseeable future.

Questions

1. What are the park's most valuable/important/significant resources of concern? (e.g., springs, alpine habitats etc.)
2. What are the park's most valuable/important/significant species of concern?
3. What are the park's most important natural resource management issues?
4. What are the greatest current threats to significant park natural resources?
5. What are the greatest potential/future threats to significant park resources?
6. Are there any historic research, inventory, or monitoring projects that you think are especially valuable in understanding the park's natural systems?
7. Are you working with other agencies/land owners on any inventory, monitoring, research, or restoration projects?
8. If you could only have one long-term monitoring project in your park, what would it be?
9. We want information produced by the Inventory and Monitoring Program to be widely interpreted. What is the best way to make this information available to interpretive staff and the public? What is the best way to make this information available to you?
10. Are there other issues that you would like to be considered in developing this monitoring program?

Thomas Heinlein, Superintendent: Bering Land Bridge National Preserve

1. **What are the park's most valuable/important/significant resources of concern?**
    - Coastal ecosystems
    - Lagoons
    - All riverine habitats and large freshwater lakes
    - Serpentine Hotsprings
    - Cultural resources (especially the Trail Creek Caves area)
    - Alpine areas (especially high-altitude lakes)
2. **What are the park's most valuable/important/significant species of concern?**
    - Vegetation communities and Shrub Expansion
    - Subsistence and sport hunting species (especially bear, muskox and moose)
    - Species in the habitats listed in Question 1
3. **What are the park's most important natural resource management issues?**
    - Consumptive uses of resources
    - Liberalization of sport hunting regulations
    - Predator control issues
    - Western Arctic Caribou Herd expansion
4. **What are the greatest current threats to significant park natural resources?**
    - Efforts by DOT to push road to Serpentine Hotsprings
    - Road to new Shishmaref, road from Tin Creek to Ear Mountain to obtain gravel for New Shishmaref Site
5. **What are the greatest potential/future threats to significant park resources?**
    - ATV traffic moving out along ad hoc trails from proposed road corridors
    - Indirect effects of North Slope industrial development (e.g., oil spills due to increased shipping in the Chukchi and Bering Seas)
6. **Are there any historic research, inventory, or monitoring projects that you think are especially valuable in understanding the park's natural systems?**
    - Geothermal dynamics at Serpentine Hotsprings
7. **Are you working with other agencies/land owners on any inventory, monitoring, research, or restoration projects?**
    - Alaska Department of Fish and Game (e.g., fish and mammals)
8. **If you could only have one long-term monitoring project in your park, what would it be?**
    - Coastal Processes
    - Coastal Erosion
    - Thermokarsting of the Landscape
9. **We want information produced by the Inventory and Monitoring Program to be widely interpreted. What is the best way to make this information available to interpretive staff and the public? What is the best way to make this information available to you?**
    - Direct presentations, mini-symposium, audiovisual presentations
10. **Are there other issues that you would like to be considered in developing this monitoring program?**
    - No additional issues

Dave Mills, Superintendent: Gates of the Arctic Park and Preserve

1. **What are the park's most valuable/important/significant resources of concern?**
   - Lakes and rivers and species within those rivers (e.g., six rivers designated Wild and Scenic)
   - Noatak River and its surrounding watershed
   - Natural processes and the wilderness character of the park
   - Spring areas (overwintering habitat for aquatic species)

2. **What are the park's most valuable/important/significant species of concern?**
   - Consumptive species (especially fish, Dall's sheep, caribou, and moose)
   - Organisms at lower trophic levels of the food chain and the processes that support them

3. **What are the park's most important natural resource management issues?**
   - Water quality
   - Air quality
   - Maintaining natural and healthy populations

4. **What are the greatest current threats to significant park natural resources?**
   - Industrial development adjacent to the park and associated transportation issues (e.g., mineral and gas deposits)
   - Global changes in atmospheric conditions

5. **What are the greatest potential/future threats to significant park resources?**
   - Indirect effects of North Slope industrial development

6. **Are there any historic research, inventory, or monitoring projects that you think are especially valuable in understanding the park's natural systems?**
   - Anaktuvuk Pass and hunting
   - Traditional ecological knowledge
   - Local knowledge of inholders

7. **Are you working with other agencies/land owners on any inventory, monitoring, research, or restoration projects?**
   - Alaska Department of Fish and Game
   - U.S. Fish and Wildlife Service
   - Local communities

8. **If you could only have one long-term monitoring project in your park, what would it be?**
   - Understanding building blocks (start low on the food chain)
   - Ecological building blocks vital to natural processes and cycles (e.g., insect biomass)
   - Water and water quality
   - Arctic vegetation

9. **We want information produced by the Inventory and Monitoring Program to be widely interpreted. What is the best way to make this information available to interpretive staff and the public? What is the best way to make this information available to you?**
   - Direct presentations to local communities
   - Meet with superintendents and regional directorate once a month (mini-symposium)
   - Films
   - Radio
   - Knowledge > understanding > appreciation

10. **Are there other issues that you would like to be considered in developing this monitoring program?**
    - Emphasize the critical nature of working with indigenous cultures
    - Involve operational staff

George Helfrich, Superintendent: Western Arctic Parklands (includes BELA, CAKR, KOVA, and NOAT)

1. **What are the park's most valuable/important/significant resources of concern? (e.g., springs, alpine habitats etc.)**
    - It is impossible to name just one or two resources of concern. We are interested in preserving whole intact ecosystems: air, water, flora, fauna. Under ANILCA, we're particularly concerned with subsistence resources. Of those, the most important is the Western Arctic Caribou Herd.
2. **What are the park's most valuable/important/significant species of concern?**
    - The parks' enabling legislations enumerate the species we are to be most concerned about.
3. **What are the park's most important natural resource management issues?**
    - Baseline data for plant and animal populations. Management of the moose population, about which we disagree with the ADFG. Predator control, about which we disagree with the state. Possible contamination of plants and animals along the Red Dog Mine haul road.
4. **What are the greatest current threats to significant park natural resources?**
    - Lack of very good knowledge about some large mammal populations and so possible over-consumption.
5. **What are the greatest potential/future threats to significant park resources?**
    - Industrialization of area around the park, affecting park ecosystems.
6. **Are there any historic research, inventory, or monitoring projects that you think are especially valuable in understanding the park's natural systems?**
    - All the past plant and animal studies and reports that provide baseline data are invaluable.
7. **Are you working with other agencies/land owners on any inventory, monitoring, research, or restoration projects?**
    - We routinely work on an ad-hoc basis with Maniilaq, the Kotzebue IRA, ADFG, USFWS, BLM, and others.
8. **If you could only have one long-term monitoring project in your park, what would it be?**
    - The obvious choice would be caribou, but many groups focus on them. Land cover would be a good choice. Bears would be another.
9. **We want information produced by the Inventory and Monitoring Program to be widely interpreted. What is the best way to make this information available to interpretive staff and the public? What is the best way to make this information available to you?**
    - Clear, focused monographs available written for the lay person, available both in paper and electronically.
10. **Are there other issues that you would like to be considered in developing this monitoring program?**
    - Resolve any deficits in the inventory program before beginning monitoring.

Appendix 2
Fish Species in the Arctic Network

Common Name	Scientific Name	BELA	CAKR	GAAR	KOVA	NOAT
Alaska Blackfish	*Dallia pectoralis*	X	X		X	X
Arctic Char	*Salvelinus alpinus*	X	X	X	X	X
Arctic Grayling	*Thymallus arcticus*	X	X	X	X	
Arctic Lamprey	*Lampetra japonica*					X
Bering Cisco	*Coregonus laurettae*	X	X			
Broad Whitefish	*Coregonus nasus*	X	X	X	X	X
Burbot	*Lota lota*		X	X	X	X
Chinook Salmon	*Oncorhynchus tshawytscha*	X	X	X	X	X
Chum Salmon	*Oncorhynchus keta*	X	X	X	X	
Coastrange Sculpin	*Cottus aleuticus*					X
Coho Salmon	*Oncorhynchus kisutch*	X	X			
Dolly Varden	*Salvelinus malma*	X	X	X	X	X
Humpback Whitefish	*Coregonus clupeaformis*		X	X	X	
Lake Trout	*Salvelinus namaycush*			X		X
Least Cisco	*Coregonus sardinella*	X	X	X	X	X
Longnose Sucker	*Catostomus catostomus*		X	X	X	X
Nine-Spine Stickleback	*Pungitius pungitius*	X	X	X	X	X
Northern Pike	*Esox lucius*		X	X	X	X
Old Man Char	*Salvelinus anaktuvukensis*			X		X
Pink Salmon	*Oncorhynchus gorbuscha*	X	X		X	X
Pond Smelt	*Hypomesus olidus*					X
Rainbow Smelt	*Osmerus mordax*					X
Round Whitefish	*Prosopium cylindraceum*		X	X		
Sheefish	*Stenodus leucichthys*		X	X	X	X
Slimy Sculpin	*Cottus cognatus*	X		X	X	X
Sockeye Salmon	*Oncorhynchus nerka*	X	X	X	X	
Three-Spine Stickleback	*Gasterosteus aculeatus*					X

Appendix 3
Vascular Plant Species of Concern in the Arctic Network

Summary list of the rare plant species documented or cited from ARCN. Included are current Alaska Natural Heritage Program rankings (see below). X indicates species presence has been documented with a voucher specimen, and * indicates species has been cited, but specimens are lacking. List created and reviewed by Carolyn Parker (University of Alaska Museum of the North Herbarium) for the ARCN Vascular Plant Inventory (2006).

Species/Rankings		BELA	CARK	GAAR	KOVA	NOAT
Aspleniaceae						
Asplenium viride	G4S3	*			*	
Asteraceae						
Artemisia senjavinensis	G3S2S3	X				
Erigeron muirii	G2S2			X		
Erigeron porsildii	G4S3			X		X
Saussurea triangulata	G1?S1				X	
Symphyotrichum yukonense	G3S3			X	X	X
Brassicaceae						
Aphragmus eschscholtzianus	G3S3			X		
Cardamine microphylla ssp. *blaisdellii*	G4S2S3	X		X	X	
Draba exalata	G3S3	X				
Draba pauciflora	G4S1			X		
Smelowskia porsildii	G5S2S3			X		X
Thlaspi arcticum	G3S3			X		
Campanulaceae						
Campanula aurita	G4S3			X		
Caryophyllaceae						
Arenaria longipedunculata	G3S3		X	X	X	X
Minuartia biflora	G5S3S4	X		X		X
Minuartia yukonensis	G4S3					X
Stellaria alaskana	G3S3			X		
Stellaria dicranoides	G3S3	X	X	X	X	X
Stellaria umbellata	G5S2S3	X		X		
Chenopodiaceae						
Corispermum ochotense var. *alaskanum*	G3G4T?QS2				X	
Cyperaceae						
Carex deflexa	G5S1S2			X		
Carex heleonastes	G4S2			X		
Carex holostoma	G4?S2	X	X			X
Carex lapponica	G4G5S2			X	X	
Eleocharis kamtschatica	G4S2S3				X	
Eriophorum viridicarinatum	G5S2			X		
Fabaceae						
Lupinus kuschei	G3S2				X	
Oxytropis arctica var. *barnebyana*	G4TS2	X	X			X
Oxytropis kobukensis	G2S2				X	
Oxytropis kokrinensis	G3S3			X	X	X

Oxytropis tananensis	G2G3QS2S3					X
Gentianaceae						
Gentianopsis detonsa ssp. *detonsa*	G3G4T?S1		X			
Orchidaceae						
Cypripedium parviflorum	G5S2S3			X		
Papaveraceae						
Papaver walpolei	G3S3	X	X		X	X
Poaceae						
X_Dupoa labradorica		X	X			
Festuca edlundiae	G3G4S1			X		
Festuca lenensis	G4G5S3		X	X	X	X
Glyceria pulchella	G5S2S3				X	
Glyceria striata ssp. *stricta*	G5S2			X		
Puccinellia vaginata	G4S1	X	X			
Puccinellia vahliana	G4S2S3			X		X
Puccinellia wrightii	G3G4S2S3	X				X
Schizachne purpurascens	G5S2			X		
Polygonaceae						
Rumex krausei	G2S2		X			X
Potamogetonaceae						
Potamogeton subsibiricus	G3S3		X			
Primulaceae						
Douglasia beringensis	G3S3	X				
Primula tschuktschorum	G2G3S2S3	X				
Pteridaceae						
Cryptogramma stelleri	G5S2S3		X		X	X
Ranunculaceae						
Oxygraphis glacialis	G4G5S2S3			X		
Ranunculus glacialis ssp. *camissonis*	G4T3T4S2	X		X		X
Ranunculus monophyllus	G5S1S2	X				X
Rosaceae						
Potentilla fragiformis	G4S1		X			
Potentilla rubricaulis	G4S2S3			X		X
Potentilla stipularis	G5S1					X
Saxifragaceae						
Saxifraga nudicaulis	G3G4QS2S3	X				
Violaceae						
Viola selkirkii	G5S3			*		
Zannichelliaceae						
Zannichellia palutris L.	G5S3		X			

Rare plant ranking abbreviations

Listed are the abbreviations used for indicating plant rarity that are used by the Nature Conservancy and a network of Natural Heritage Programs and Conservation Data Centers. In Alaska, the Alaska Natural Heritage Program, University of Alaska Anchorage, maintains a tracking list and rankings for the rare biota of Alaska.

G# = global rank, throughout the entire range of the species
S# = state rank, rarity as observed at the state level
1 = species is critically imperiled due to extreme rarity (five or fewer occurrences), or due to some factor of its biology making it especially vulnerable to extinction
2 = species is imperiled due to rarity (six to 20 occurrences), or due to other factors making it very vulnerable to extinction
3 = species is either very rare and local in distribution (21 to 100 occurrences) or found within a restricted range
4 = species is widespread and apparently secure
5 = species is clearly secure
S#S# = indicates rank is uncertain and best described as a range between two rankings
T = indicates ranking is for the listed subspecies or variety

Appendix 4

Bird Species in the Arctic Network

Common name	Scientific name	BELA	CAKR	GAAR	KOVA	NOAT
Alder Flycatcher	*Empidonax alnorum*	X		X	X	X
Aleutian Tern	*Sterna aleutica*	X	X			
American Dipper	*Cinclus mexicanus*				X	
American Golden-Plover	*Pluvialis dominica*	X	X	X	X	X
American Kestrel	*Falco sparverius*			X	X	X
American Pipit	*Anthus rubescens*	X	X	X	X	X
American Robin	*Turdus migratorius*	X	X	X	X	X
American Tree Sparrow	*Spizella arborea*	X	X	X	X	X
American Wigeon	*Anas americana*	X		X	X	X
Arctic Tern	*Sterna paradisaea*	X	X	X	X	X
Arctic Warbler	*Phylloscopus borealis*	X	X	X	X	X
Baird's Sandpiper	*Calidris bairdii*	X	X	X	X	X
Bald Eagle	*Haliaeetus leucocephalus*	X	X	X	X	
Bank Swallow	*Riparia riparia*	X	X	X	X	X
Barn Swallow	*Hirundo rustica*	X				
Barrow's Goldeneye	*Bucephala islandica*	X				
Bar-tailed Godwit	*Limosa lapponica*	X	X	X		X
Belted Kingfisher	*Ceryle alcyon*			X	X	X
Black Guillemot	*Cepphus grylle*	X				
Black Scoter	*Melanitta nigra*	X	X	X	X	X
Black Turnstone	*Arenaria melanocephala*	X	X			X
Black-bellied Plover	*Pluvialis squatarola*	X	X	X		X
Black-capped Chickadee	*Parus atricapillus*			X	X	
Black-legged Kittiwake	*Rissa tridactyla*	X	X			
Blackpoll Warbler	*Dendroica striata*	X	X	X	X	X
Bluethroat	*Luscinia svecica*	X	X	X	X	X
Bohemian Waxwing	*Bombycilla garrulous*		X	X	X	X
Bonaparte's Gull	*Larus philadelphia*	X	X	X	X	X
Boreal Chickadee	*Poecile hudsonicus*		X	X	X	X
Boreal Owl	*Aegolius funereus*			X	X	
Brant	*Branta bernicla*	X	X			X
Bristle-thighed Curlew	*Numenius tahitiensis*	X	X			X
Buff-breasted Sandpiper	*Tryngites subruficollis*		X			X
Bufflehead	*Bucephala albeola*	X		X		X
Canada Goose	*Branta canadensis*	X	X	X	X	X
Canvasback	*Aythya valisineria*	X	X	X		X
Cliff Swallow	*Hirundo pyrrhonota*	X		X	X	X
Common Eider	*Somateria mollissima*	X	X			
Common Goldeneye	*Bucephala clangula*	X		X		
Common Loon	*Gavia immer*	X	X	X	X	X
Common Merganser	*Mergus merganser*	X	X	X	X	X

Common name	Scientific name	BELA	CAKR	GAAR	KOVA	NOAT
Common Murre	*Uria aalge*	X	X			
Common Raven	*Corvus corax*	X	X	X	X	X
Common Redpoll	*Carduelis flammea*	X	X	X	X	X
Crested Auklet	*Aethia cristatella*	X				
Dark-eyed Junco	*Junco hyemalis*	X	X	X	X	X
Downy Woodpecker	*Picoides pubescens*	X				
Dunlin	*Calidris alpine*	X	X			
Emperor Goose	*Chen canagica*	X				
Eurasian Wigeon	*Anas penelope*	X				
Fox Sparrow	*Passerella iliaca*	X	X	X	X	X
Glaucous Gull	*Larus hyperboreus*	X	X	X	X	X
Glaucous-winged Gull	*Larus glaucescens*	X	X			
Golden Eagle	*Aquila chrysaetos*	X	X	X	X	X
Golden-crowned Sparrow	*Zonotrichia atricapilla*	X	X	X	X	X
Gray Jay	*Perisoreus canadensis*		X	X	X	X
Gray-cheeked Thrush	*Catharus minimus*	X	X	X	X	X
Gray-crowned Rosy-Finch	*Leucosticte tephrocotis*		X	X	X	X
Great Gray Owl	*Strix nebulosa*		X	X	X	
Greater Scaup	*Anas marila*	X	X	X	X	X
Greater White-fronted Goose	*Anser albifrons*	X	X	X	X	X
Greater Yellowlegs	*Tringa melanoleuca*			X		X
Green-winged Teal	*Anas crecca*	X	X	X	X	X
Gyrfalcon	*Falco rusticolus*	X	X	X	X	X
Hairy Woodpecker	*Picoides villosus*			X		
Harlequin Duck	*Histrionicus histrionicus*	X	X	X	X	
Hermit Thrush	*Catharus guttatus*		X			X
Herring Gull	*Larus argentatus*	X	X	X	X	X
Hoary Redpoll	*Carduelis hornemanni*		X	X	X	X
Horned Grebe	*Podiceps auritus*	X	X	X	X	X
Horned Lark	*Eremophila alpestris*	X	X	X	X	X
Horned Puffin	*Fratercula corniculata*	X	X			
Hudsonian Godwit	*Limosa haemastica*	X	X			X
Ivory Gull	*Pagophila eburnea*		X			
King Eider	*Somateria spectabilis*	X	X			
Kittlitz's Murrelet	*Brachyramphus brevirostris*		X			
Lapland Longspur	*Calcarius lapponicus*	X	X	X	X	X
Least Auklet	*Aethia pusilla*	X				
Least Sandpiper	*Calidris minutilla*	X	X	X	X	X
Lesser Scaup	*Aythya affinis*	X	X	X	X	
Lesser Yellowlegs	*Tringa flavipes*		X	X	X	X
Lincoln's Sparrow	*Melospiza lincolnii*	X		X	X	X
Long-billed Dowitcher	*Limnodromous scolopaceus*	X	X	X	X	X
Long-tailed Duck	*Clangula hyemalis*	X	X	X	X	X
Long-tailed Jaeger	*Stercorarius longicaudus*	X	X	X	X	X
Mallard	*Anas platyrhynchos*	X	X	X	X	X
Merlin	*Falco columbarius*	X	X	X	X	X

Common name	Scientific name	BELA	CAKR	GAAR	KOVA	NOAT
Mew Gull	*Larus canus*	X	X	X	X	X
Northern Flicker	*Colaptes auratus*	X		X	X	X
Northern Goshawk	*Accipiter gentiles*		X	X		X
Northern Harrier	*Circus cyaneus*	X	X	X	X	X
Northern Hawk Owl	*Surnia ulula*		X	X	X	X
Northern Pintail	*Anas acuta*	X	X	X	X	X
Northern Shoveler	*Anas clypeata*	X	X	X	X	X
Northern Shrike	*Lanius excubitor*	X	X	X	X	X
Northern Waterthrush	*Seiurus noveboracensis*	X	X	X	X	X
Northern Wheatear	*Oenanthe oenanthe*	X	X	X	X	X
Olive-sided Flycatcher	*Contopus cooperi*			X	X	X
Orange-crowned Warbler	*Vermivora celata*	X	X	X	X	X
Osprey	*Pandion haliaetus*	X		X	X	X
Pacific Golden-Plover	*Pluvialis fulva*					X
Pacific Loon	*Gavia pacifica*	X	X	X	X	X
Parakeet Auklet	*Cyclorrhynchus psittacula*	X				
Parasitic Jaeger	*Stercorarius parasiticus*	X	X	X	X	X
Short-tailed Shearwater	*Puffinus tenuirostris*		X			
Pectoral Sandpiper	*Calidris melanotos*	X	X	X	X	X
Pelagic Cormorant	*Phalacrocorax pelagicus*	X	X			
Peregrine Falcon	*Falco peregrinus*	X	X	X	X	X
Pigeon Guillemot	*Cepphus columba*		X			
Pine Grosbeak	*Pinicola enucleator*			X	X	X
Pine Siskin	*Carduelis pinus*			X		
Pomarine Jaeger	*Stercorarius pomarinus*	X	X		X	X
Red Knot	*Calidris canutus*		X	X		X
Red Phalarope	*Phalaropus fulicarius*	X	X	X		
Red-breasted Merganser	*Mergus serrator*	X	X	X	X	X
Red-breasted Nuthatch	*Sitta canadensis*			X		
Redhead	*Aythya americana*	X				
Red-necked Grebe	*Podiceps grisegena*	X	X	X	X	X
Red-necked Phalarope	*Phalaropus lobatus*	X	X	X	X	X
Red-tailed Hawk	*Buteo jamaicensis*			X		X
Red-throated Loon	*Gavia stellata*	X	X	X	X	X
Red-throated Pipit	*Anthus cervinus*	X				
Rock Ptarmigan	*Lagpus mutus*	X	X	X	X	X
Rock Sandpiper	*Calidris ptilocnemis*	X	X			
Rosy Finch	*Leucosticte arctoa*		X	X		X
Rough-legged Hawk	*Buteo lagopus*	X	X	X	X	X
Ruby-crowned Kinglet	*Regulus calendula*		X	X	X	X
Ruddy Turnstone	*Arenaria interpres*	X	X			X
Rusty Blackbird	*Euphagus carolinus*	X	X	X	X	X
Sabine's Gull	*Xema sabini*	X	X			
Sanderling	*Calidris alba*	X	X	X	X	
Sandhill crane	*Grus canadensis*	X	X	X	X	X
Savannah Sparrow	*Passerculus sandwichensis*	X	X	X	X	X

Common name	Scientific name	BELA	CAKR	GAAR	KOVA	NOAT
Say's Phoebe	*Sayornis saya*	X	X	X	X	X
Semipalmated Plover	*Charadrius semipalmatus*	X	X	X	X	X
Semipalmated Sandpiper	*Calidris pusila*	X	X		X	X
Sharp-shinned Hawk	*Accipiter striatus*	X			X	X
Sharp-tailed Sandpiper	*Calidris acuminata*		X			
Short-eared Owl	*Asio flammeus*	X	X	X	X	X
Siberian Tit	*Parus cinctus*				X	X
Smith's Longspur	*Calcarius pictus*			X		X
Snow Bunting	*Plectrophenax nivalis*	X	X	X	X	X
Snow Goose	*Chen caerulescens*	X	X	X	X	
Snowy Owl	*Nyctea scandiaca*	X	X	X	X	
Solitary Sandpiper	*Tringa solitaria*			X	X	X
Spectacled Eider	*Somateria fischeri*	X	X			
Spotted Sandpiper	*Actitis macularia*		X	X	X	X
Spruce Grouse	*Falcipennis canadensis*		X	X	X	X
Steller's Eider	*Polysticta stelleri*		X			
Surf Scoter	*Melanitta perspicillata*	X	X	X	X	X
Surfbird	*Aphriza virgata*			X	X	X
Swainson's Thrush	*Catharus ustulatus*			X	X	X
Thick-billed Murre	*Uria lomvia*	X	X			
Three-toed Woodpecker	*Picoides tridactylus*			X		X
Townsend's Solitaire	*Myadestes townsendi*			X		
Tree Swallow	*Tachycineta bicolor*	X	X	X	X	X
Tufted Puffin	*Fratercula cirrhata*		X			
Tundra Swan	*Cygnus columbianus*	X	X	X	X	X
Upland Sandpiper	*Bartramia longicauda*			X		X
Varied Thrush	*Ixoreus naevius*	X	X	X	X	X
Violet-green Swallow	*Tachycineta thalassina*			X	X	
Wandering Tattler	*Heteroscelus incanus*	X	X	X	X	X
Western Sandpiper	*Calidris mauri*	X	X			X
Western Wood-pewee	*Contopus sordidulus*					X
Whimbrel	*Numenius phaeopus*	X	X	X	X	X
White Wagtail	*Motacilla alba*	X	X			
White-crowned Sparrow	*Zonotrichia leucophrys*	X	X	X	X	X
White-winged Crossbill	*Loxia leucoptera*			X	X	
White-winged Scoter	*Melanitta fusca*	X	X	X		X
Willow Ptarmigan	*Lagopus lagopus*	X	X	X	X	X
Wilson's Snipe	*Gallinago delicate*	X	X	X	X	X
Wilson's Warbler	*Wilsonia pusilla*	X	X	X	X	X
Yellow Wagtail	*Motacilla flava*	X	X	X	X	X
Yellow Warbler	*Dendroica petechia*	X	X	X	X	X
Yellow-billed Loon	*Gavia adamsii*	X	X	X		X
Yellow-rumped Warbler	*Dendroica coronata*		X	X	X	X
Totals		129	132	129	114	126

Appendix 5
Mammal Species in the Arctic Network

Scientific Name	Common Name	GAAR	NOAT	KOVA	CAKR	BELA
Ovibos moschatus	muskox	X	X	X	X	X
Ovis dalli	Dall's sheep	X	X	X	X	
Alces alces	moose	X	X	X	X	X
Rangifer tarandus	caribou	X	X	X	X	X
Alopex lagopus	Arctic fox	X	X	X		
Canis latrans	coyote	X				
Canis lupus	wolf	X	X	X	X	X
Vulpes vulpes	red fox	X	X	X	X	X
Lynx canadensis	lynx	X	X	X	X	X
Gulo gulo	wolverine	X	X	X	X	X
Lontra canadensis	river otter	X	X	X	X	
Martes americana	marten	X	X	X		
Mustela erminea	ermine	X	X	X	X	X
Mustela nivalis	least weasel	X	X	X	X	
Mustela vison	mink	X	X	X		
Ursus americanus	black bear	X	X	X		
Ursus arctos	grizzly bear	X	X	X	X	X
Sorex arcticus	Arctic shrew	X	X	X		
Sorex cinereus	cinerous shrew	X	X	X	X	X
Sorex hoyi	pygmy shrew	X	X	X		
Sorex monticolus	montane shrew	X	X	X	X	X
Sorex tundrensis	tundra shrew	X	X	X	X	X
Sorex ugyunak	barren ground shrew	X	X	X	X	X
Sorex yukonicus	tiny shrew	X	X	X	X	
Lepus americanus	snowshoe hare	X	X	X	X	
Lepus othus	Arctic hare	X	X			
Castor canadensis	beaver	X	X	X	X	
Erethizon dorsatum	porcupine	X	X	X	X	X
Clethrionomys rutilus	red-backed vole	X	X	X	X	X
Dicrostonyx groenlandicus	collared lemming	X	X	X	X	X
Lemmus trimucronatus	brown lemming	X	X	X	X	X
Microtus miurus	singing vole	X	X	X	X	X
Microtus oeconomus	tundra vole	X	X	X	X	X
Microtus pennsylvanicus	meadow vole	X				
Microtus xanthognathus	yellow-cheeked vole	X	X	X		
Ondatra zibethicus	muskrat	X	X	X	X	X
Synaptomys borealis	northern bog lemming	X	X			
Marmota broweri	Alaska marmot	X	X	X		
Spermophilus parryii	Arctic ground squirrel	X	X	X	X	X
Tamiasciurus hudsonicus	red squirrel	X	X	X	X	

Appendix 6
Summary of Monitoring Activities in ARCN

United States Geological Survey (http://www.ecotrust.org/copperriver/crks_cd/content/data_and_software/metadata/landcov/vegclass_1k.htm)
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Categories: Land Use/Landcover Change, Vegetation (general)
Vital Sign: Land Use and Cover
Summary: Vegetation map in grid format developed for the state of Alaska by Michael Fleming, USFS/USGS, using using the phenology of a vegetation index (AVHRR/NDVI) collected during the 1991 growing season. 1000 km cell size, scale 1:2,500,000.

Alaska-Yukon Arctic Ecoregional Assessment
The Nature Conservancy (http://nature.org/wherewework/northamerica/states/alaska/preserves/art13301.html)
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Categories: Biodiversity, Birds, GIS datasets, Large Mammals, Management Concern, Small Mammals
Vital Signs: Land Use and Cover, At-risk Biota, Focal Species or Communities
Summary: One of the products of the Alaska-Yukon Arctic ecoregional assessment is a map indicating areas of biological significance. Referred to as a portfolio, this map is based on the best available information on the distribution, goals, and viability of selected conservation targets, and it represents areas that, if managed for biodiversity, will likely conserve the native species and ecological communities of the ecoregion. The portfolio is a conservation blueprint – a vision for conservation success – to guide public land managers, conservation organizations, private landowners, and others in conserving natural diversity within the ecoregion. This update describes how we designed a conservation portfolio for the Alaska-Yukon Arctic ecoregion. We address the methods used, the strengths and weaknesses of approaches, and conclusions that can be drawn from the portfolio.

Alaska Department of Fish and Game, Division of Wildlife Conservation
Alaska Department of Fish and Game (http://www.wildlife.alaska.gov/)
Dataset Type: Long-term monitoring (2+ years)
Ecological Category: Large Mammals
Vital Signs: Consumptive Use, Focal Species or Communities
Summary: The Division of Wildlife Conservation recognizes wildlife as a public trust belonging to all Alaskans and is an organization of individuals committed to interacting professionally with one another and the public and to using scientific data and public input to conserve Alaska's wildlife.

Alaska Department of Fish and Game: Alaska Freshwater Fish Inventory
Alaska Department of Fish and Game *(http://www.sf.adfg.state.ak.us/SARR/FishDistrib/FDD_catalogs.cfm)*
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Fish
Vital Sign: Focal Species or Communities
Summary: The Fish Distribution Database/Anadromous Waters Catalog and Atlas (FDD) is the regulatory tool established by statute to specify the various rivers, lakes, and streams of Alaska that are important to the spawning, rearing, or migration of anadromous fishes.

Alaska Department of Fish and Game's Anadromous Streams data
Alaska Department of Fish and Game *(http://www.sf.adfg.state.ak.us/SARR/FishDistrib/FDD_catalogs.cfm)*
Dataset Type: Biological Inventory
Ecological Category: Fish
Vital Sign: Focal Species or Communities
Summary: The Alaska Department of Fish and Game's (ADF&G) Anadromous Streams data is derived from the ADF&G's GIS shapefiles for the "Catalog of Waters Important for Spawning, Rearing or Migration of Anadromous Fishes" (referred to as the "Catalog") and the "Atlas to the Catalog of Waters Important for Spawning, Rearing or Migration of Anadromous Fishes" (referred to as the "Atlas"). It is produced for general visual reference and to aid users in generating various natural resource analyses and products. The data depict the known anadromous fish bearing lakes and streams within Alaska from the mouth to the known upper extent of species usage.

Alaska Landbird Resource Information System
Partners In Flight *(http://www.partnersinflight.org/description.cfm)*
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Birds
Vital Sign: Focal Species or Communities
Summary: Partners In Flight was launched in 1990 in response to growing concerns about declines in the populations of many land bird species, and in order to emphasize the conservation of birds not covered by existing conservation initiatives. The initial focus was on neotropical migrants, species that breed in the Nearctic (North America) and winter in the Neotropics (Central and South America), but the focus has spread to include most landbirds and other species requiring terrestrial habitats. The central premise of Partners In Flight (PIF) has been that the resources of public and private organizations in North and South America must be combined, coordinated, and increased in order to achieve success in conserving bird populations in this hemisphere. Partners In Flight is a cooperative effort involving partnerships among federal, state and local government agencies, philanthropic foundations, professional organizations, conservation groups, industry, the academic community, and private individuals.

Alaska Natural Heritage Program
Alaska Natural Heritage Program *(http://aknhp.uaa.alaska.edu/Default.htm)*
Dataset Type: Biological inventory
Ecological Categories: Amphibians, Biodiversity, Birds, Fish, Invasive Species, Large Mammals, Management Concern, Small Mammals, Vascular Plants, Vegetation (general)
Vital Signs: At-risk Biota, Invasive Species
Summary: The Alaska Natural Heritage Program (AKNHP) is Alaska's clearinghouse for information on plant and animal species of conservation concern, natural communities of conservation concern, and invasive nonnative plant species. We collect, validate, and distribute this information, and assist natural resource managers and others in applying it effectively.

Arctic Network Biological Inventories
National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Categories: Birds, Large Mammals, Small Mammals, Vascular Plants
Vital Sign: Focal Species or Communities
Summary: Baseline inventories conducted by the Arctic Network include birds, vascular plants and mammals. These data will be incorporated into the national Inventory & Monitoring data store, NPSpecies in 2005.

Arctic Transitions in the Land-Atmosphere System Climate Stations
Water and Environmental Research Center *(http://www.uaf.edu/water/projects/atlas/proposal.html)*
Dataset Type: Long-term Monitoring
Ecological Category: Climate/Weather/Climate Change
Vital Sign: Weather
Summary: Originated in 1998 as a logical outgrowth of prior FLUX studies, Arctic Transitions in the Land-Atmosphere System (ATLAS) is a coordinated program to examine the geographical patterns and controls over climate-land surface exchange and develop reasonable scenarios of future change in the Arctic. There are six climate stations for the program located on the Seward Peninsula.

Environmental Protection Agency's Monitoring and Assessing Water Quality website (STORET)
Environmental Protection Agency *(http://www.epa.gov/storet/dbtop.html)*
Dataset Type: Long-term Monitoring
Ecological Categories: Contaminants, Water Quality/Biota/Chemistry
Vital Sign: Water Quality
Summary: The U.S. Environmental Protection Agency (EPA) maintains two data management systems containing water quality information for the nation's waters: the Legacy Data Center (LDC), and STORET. The LDC is a static, archived database and STORET is an operational system actively being populated with water quality data.

Forest Insect & Disease Conditions in Alaska
Alaska Department of Natural Resources, Division of Forestry *(http://agdc.usgs.gov/data/projects/fhm/index.html)*
Dataset Type: Long-term monitoring (2+ years)
Ecological Category: Disease/Parasites
Vital Sign: Infestations and Disease
Summary: The Forest Insect & Disease Conditions in Alaska dataset represents areas of forest damage due to insect infestation, disease, winter damage, fire, flood, landslides, and windthrow. The information was collected, cooperatively by aerial surveys by both the USFS, Forest Health Protection (FHP) and Alaska Department of Natural Resources, Division of Forestry. Surveys are conducted primarily in July and August so that pest "signatures" may be identified during the optimal period for symptom development of ocular estimation. The aerial survey is coordinated such that the maximum extent of recent bark beetle damage (fading trees) and insect defoliation (discoloration, foliage loss) patterns may be determined. Aerial survey flights are termed as "local" if they can be completed within 1 day from the survey base and "regional" if more than one day is required to complete the survey reconnaissance. Surveys are flown in Southeast Alaska, Southcentral Alaska and Interior Alaska.

Kobuk Landscape Study database
National Park Service
Dataset Type: Biological inventory
Ecological Category: Land Use/Landcover Change
Vital Signs: Land Use and Cover, Soil Quality
Summary: The Kobuk Landscape Study was initiated by the National Park Service in 1992 in cooperation with the Natural Resources Conservation Service (then Soil Conservation Service) to collect baseline data on the soils and vegetation in the Kobuk Preserve portion of Gates of the Arctic National Park and Preserve. This information was important in the event a road should be built through the Preserve into the Ambler Mining District to the west of the park. Field work for the project was conducted during the summers of 1992 and 1993 by David K. Swanson of the Soil Conservation Service and Donna L. DeVoe of the National Park Service. Soils and vegetation data were collected from soil pits and area immediately surrounding the pits. Notes on animal activity at these sites were also kept (mostly caribou, voles/small mammals, and birds). An auger and shovel were used to dig sizable soil pits to obtain full description of the soil layers underneath the surface. Pits were dug as deep as possible, reaching to approximately three to four feet deep, or to bedrock. At each soil pit, a general description of the vegetation was noted using Viereck's system for classifying vegetation (Viereck et al. 1992. The Alaska Vegetation Classification. Gen. Tech. Rep. PNW-GTR-286. U.S. Dept. of Agriculture, Forest Service). At selected sites, a more detailed description of the vegetation was collected, where all species found within a circumference of about 20m from the soil pit were listed along with an estimate of percent cover for each species. Color infrared aerial photos were used to plan transect locations, and also to mark soil pit locations by pin pricks made in the photos. These pin pricks were later transferred onto paper topographic maps (1:63,360 scale). Soil data were used to delineate regions of soil classes within the Kobuk Preserve Unit on mylar sheets overlaid on topographic maps. These soil classes were later digitized and added to the Park's GIS.

Kobuk Preserve Unit Soils Data Collected in 1992–3 by SCS and NPS
National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Soils (Chemistry, Erosion, Contaminants, etc.)
Vital Sign: Soil Quality
Summary: Field data collected for study undertaken by the Soil Conservation Service (SCS) at the request of the National Park Service (NPS) to provide basic information about the Kobuk Preserve Unit through integrated study of landforms, soils, and vegetation. Fieldwork was completed in 1992-93 by David K. Swanson (SCS) and Donna Devoe (NPS). Data was automated in 1994 by Resource Data, Inc. for the National Park Service, AKSO.

Landcover: 2004 Bering Land Bridge NP and Cape Krusenstern NM
National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Land Use/Landcover Change
Vital Sign: Land Use and Cover
Summary: Landcover map of Bering Land Bridge National Preserve and Cape Krusenstern National Monument created for the National Park Service showing ecotypes (local-scale ecosystems) that combine physiography (i.e., coastal, riverine, alpine), bedrock geology, topography (DEM modeling), and spectral characteristics of vegetation derived from image processing (ERDAS 8.6). Ecotypes are modeled from supervised spectral classification and vector layers that best partition geomorphic, hydrologic, pedologic, and vegetative characteristics of the area. Map Sources: Landsat TM Images from 28 June 2000, 1 Aug 2002, 3 Aug 2002; Ecological Subsections map from NPS for physiography

and bedrock geology; USGS National Elevation Dataset for elevation, slope, and moisture index. Map Projection: Albers Conical Equal Area; NAD 27 datum. Map prepared by ABR, Inc. File: BELA_Ecotype_02-329-7.mxd, 6 October 2004

Landcover Map of Bering Land Bridge National Preserve
National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Land Use/Landcover Change
Vital Sign: Land Use and Cover
Summary: A 15 class landcover map of the Bering Land Bridge National Preserve and surrounding area produced from Landsat satellite imagery.

Landcover Map of Cape Krusenstern National Monument
National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Land Use/Landcover Change
Vital Sign: Land Use and Cover
Summary: Landcover map of the Cape Krusenstern area developed in 1991 from thematic mapper satellite imagery by NPS Alaska System Regional Office. Imagery used had 30 meter spatial resolution.

Landcover Map of Gates of the Arctic National Park and Preserve
National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Land Use/Landcover Change
Vital Sign: Land Use and Cover
Summary: Unfiltered (pixel level) thirty mapping class land cover product from the GAAR Land Cover Mapping Project (1997-1999) completed by Earth Satellite Corporation and Alaska Natural Heritage Program under contract with National Park Service Alaska Regional Office (NPS-AKSO) as part of NPS's Land Cover Mapping Program.

Landcover Map of Kobuk Valley National Park
National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Land Use/Landcover Change
Vital Sign: Land Use and Cover
Summary: A landcover map of Kobuk Valley area was developed in 1994 from Thematic Mapper satellite imagery by the NPS Alaska System Regional Office. The imagery has 30 meter spatial resolution.

Landcover Map of Northwestern Parks
National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Land Use/Landcover Change
Vital Sign: Land Use and Cover
Summary: A 20 class landcover map for the Northwest Areas parks of Cape Krusenstern, Kobuk Valley and Noatak. Landsat thematic mapper imagery was used. Field observations, aerial photography, and other GIS data were used to refine the map.

National Atmospheric Deposition Program/National Trends Network Monitoring Location AK99
National Atmospheric Deposition Program (http://nadp.sws.uiuc.edu/sites/siteinfo.asp?net=NTN&id=AK99)
Dataset Type: Long-term monitoring (2+ years)
Ecological Categories: Air Chemistry, Biogeochemical Processes, Contaminants
Vital Signs: Air Quality, Weather, Non-point Source Human Effects
Summary: The National Atmospheric Deposition Program/National Trends Network Monitoring in cooperation with the National Park Service set up an air chemistry monitoring station near Ambler in May 2004.

National Snow and Ice Data Center
National Snow and Ice Data Center (http://nsidc.org/data/)
Dataset Type: Long-term monitoring (2+ years)
Ecological Category: Climate/Weather/Climate Change
Vital Signs: Hydrology, Weather
Summary: NSIDC is part of the University of Colorado Cooperative Institute for Research in Environmental Sciences, and is affiliated with the National Oceanic and Atmospheric Administration National Geophysical Data Center through a cooperative agreement. NSIDC serves as one of eight Distributed Active Archive Centers funded by the National Aeronautics and Space Administration to archive and distribute data from NASA's past and current satellites and field measurement programs. NSIDC also supports the National Science Foundation through the Arctic System Science Data Coordination Center and the Antarctic Glaciological Data Center.

North America Landcover Characteristics Data Base Version 2.0
National Aeronautics and Space Administration (http://edcdaac.usgs.gov/glcc/nadoc2_0.asp - data)
Dataset Type: Long-term monitoring (2+ years)
Ecological Category: Land Use/Landcover Change
Vital Sign: Land Use and Cover
Summary: The Land Processes Distributed Active Archive Center (LP DAAC) was established as part of NASA's Earth Observing System (EOS) Data and Information System (EOSDIS) initiative to process, archive, and distribute land-related data collected by EOS sensors, thereby promoting the interdisciplinary study and understanding of the integrated Earth system.

North American Breeding Bird Survey
United States Geological Survey (http://www.pwrc.usgs.gov/bbs/)
Dataset Type: Historical inventory or monitoring data with adequate documentation
Ecological Category: Birds
Vital Sign: Focal Species or Communities
Summary: The North American Breeding Bird Survey (BBS) is a cooperative effort between the U.S. Geological Survey's Patuxent Wildlife Research Center and the Canadian Wildlife Service's National Wildlife Research Centre to monitor the status and trends of North American bird populations. Following a rigorous protocol, BBS data are collected by thousands of dedicated participants along thousands of randomly established roadside routes throughout the continent. Professional BBS coordinators and data managers work closely with researchers and statisticians to compile and deliver these population data and population trend analyses on more than 400 bird species, for use by conservation managers, scientists, and the general public.

Northwest Arctic Alaska Environmental Sensitivity Index Maps
National Oceanic and Atmospheric Administration *(http://response.restoration.noaa.gov/esi/esiintro.html)*
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Categories: At-Risk Populations/Biota, Land Use/Landcover Change, Management Concern
Vital Sign: Point-Source Human Effects
Summary: The most widely used approach to sensitive environment mapping in the United States is NOAA's Environmental Sensitivity Index (ESI). This approach systematically compiles information in standard formats for coastal shoreline sensitivity, biological resources, and human-use resources. ESI maps are useful for identifying sensitive resources before a spill occurs so that protection priorities can be established and cleanup strategies designed in advance. Using ESIs in spill response and planning reduces the environmental consequences of the spill and cleanup efforts.

NPS FirePro Dataset
National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Fire
Vital Sign: Fire
Summary: The fire effects paired plot project began in 1983 under the direction of Gary Ahlstrand, NPS Alaska regional research ecologist. Fire staff established paired vegetation plots in burned and representative unburned habitat adjacent to the burned areas of varying ages. Some plots were established in front of active wildfires. Between 1983 and 1988, approximately 485 plots were installed across nine different parks in Alaska. A total of 159 plots were established in the Arctic Network. Some of the plot locations were permanently marked; it is unknown how many plots were permanently marked in the Arctic Network Parks. Plot data collected include photographic slides of plot, density of trees and tall shrubs (Betula, Salix and Alnus) by diameter size class and species on 15-m x 30-m quadrats, vegetation cover class for 30 Daubenmire frames (20 x 50 cm), tree cores/cookies, fuels and soils data (on some plots), and general plot location descriptions. Some of the plot data in the ARCN network have been entered into a database and plot locations have been digitized off of hard-copy maps for NOAT and KOVA.

FirePro Ground Truth and Intensive Mapping Areas/Units

Fire staff collected vegetation data from sites throughout the ARCN during the late 1980s and early 1990s. Vegetation type and percent cover, landform, drainage, slope, aspect, and soils data were collected for two types of sites: Intensive Mapping Areas/Units (IMAs/IMUs) polygons and Ground Truth (GT) sites. The site locations were selected from aerial photographs that would provide representative vegetation types for mapping. Ground truth sites were assessed from the ground and aerially. Intensive Mapping Areas were polygons that were assessed from the air. Photos were taken for almost all of the plots. Plot locations were digitized and the data set has been entered into an Access database and is available as an ArcView to Access Field Data Viewer. These data were used to create final land cover maps for the GIS Thematic Mapper Landcover Mapping Project.

Additional Fire Effects Plots

Between 1978 and 1982, Chuck Racine and his colleagues established a series of plots for monitoring vegetation and permafrost recovery post fire in Noatak National Preserve and Bering Land Bridge National Preserve. In 2001–02, Racine and co-workers resampled the Imuruk Lake plots in Bering Land Bridge National Park. During 1981 and 1982, eight tundra post-fire plot sites were established in the Noatak NP in burned areas of varying ages, ranging from two to four weeks, four to five years, and 10 years post fire (1972, 1977, and 1982 fires). In addition, NPS fire staff established six plots in 2004 on the Uvgoon Creek Fire in Noatak. As part of the Arctic Network Inventory and Monitoring Program, Racine and NPS personnel propose to relocate and resample the Noatak fire plots established in 1981–82 and newly established plots by NPS staff in 2004. Remeasurements of the plots during the summer of 2005 would provide a 33-, 28-, 23-, and 1-year comparative perspective on vegetation and permafrost recovery post fire in Noatak. Data collected included (1) vertical ocular estimates of species cover, height, and stem density in 10 plots, 1 m by 1 m, at each site, (2) biomass, production, and fuel estimates made by clipping all above ground plant material in 32 cm diameter rings (804 cm^2) (four to six rings per site), (3) measurement of thaw depths, (4) shrub density, (5) photos.

NPS Historic Fire Boundaries Dataset
National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Fire
Vital Sign: Fire
Summary: Coverage containing historic ignition points of fires that have burned within park boundaries from 1956 to 2004. Data were compiled from Alaska Fire Service, BLM and the State of Alaska Department of Forestry (DoF), and National Park Service park records. Point coordinates were recorded on Fire Report sheets and are of variable quality.

NPS Lakes Inventory
National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Categories: Lake Features & Processes, Wetland (distribution and abundance)
Vital Sign: Hydrology
Summary: Statewide lakes were assembled from seventeen separate files in the USGS 1:2,000,000 Digital Line Graphs (DLG) dataset and include only those polygons with AREA greater than 20 acres (80,940 square meters).

NPS Natural Large Mammal Surveys
National Park Service
Dataset Type: Long-term monitoring (2+ years)
Ecological Category: Large Mammals
Vital Signs: Focal Species or Communities, Consumptive Use
Summary: The National Park Service monitors populations of large mammals annually in the western arctic parklands and Gates of the Arctic National Park and Preserve. Monitored species include moose, sheep and muskox. Some historical surveys exist for other mammals such as wolf and wolverine.

NPS Surficial Geology Dataset
National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Geology
Vital Sign: Geomorphology
Summary: Geology information for the Arctic Network is available through the Alaska Region spatial data stack. Information is available for GAAR, Kobuk River Basin, and Kobuk Dunes.

Red Dog Mine Site Air Monitoring
Teck Cominco *(http://arcticcircle.uconn.edu/SEEJ/RedDog/alaska_dec/reporttext.pdf)*
Dataset Type: Long-term monitoring
Ecological Category: Air Chemistry
Vital Sign: Air Quality
Summary: Teck Cominco conducts several types of air monitoring in the mine area to evaluate the effectiveness of operational controls in minimizing emissions, and to ensure compliance with their air permit. This monitoring includes EPA Methods 22 and 9. EPA Method 22 is a visible dust emission evaluation method that measures the absence or presence of dust over a period of time. Method 9 measures the opacity of a source. All samplers were operated for sampling periods of approximately 24 hours every other day, and monitoring data was submitted to DEC monthly.

Remote Automated Weather Stations (RAWS)
National Interagency Fire Center (NIFC) *(http://raws.wrh.noaa.gov/roman/)*
Dataset Type: Long-term monitoring (2+ years)
Ecological Categories: Climate/Weather/Climate Change, Fire
Vital Sign: Weather
Summary: There are nearly 1,500 interagency Remote Automated Weather Stations (RAWS) strategically located throughout the United States and managed by the National Interagency Fire Center (NIFC). Weather data assists land management agencies with a variety of projects: monitoring air quality, rating fire danger, and providing information for research applications.

SNOTEL Data Network
NRCS National Water and Climate Center *(http://www.wcc.nrcs.usda.gov/snotel/Alaska/alaska.html)*
Dataset Type: Long-term Monitoring
Ecological Category: Climate/Weather/Climate Change
Vital Sign: Weather
Summary: The National Water and Climate Center provides real-time snow and climate data using automated remote sensing from sites in the mountainous regions of the Western United States. Here you will find state and site specific data, maps and graphs showing snow water equivalent, snow depth, precipitation, temperature and other climatic elements in hourly, daily, monthly and yearly increments. These products are used for forecasting and management of water supplies.

Soil Survey Tabular Database for Kobuk Preserve Unit, Gates of the Arctic National Park, Alaska
NRCS National Water and Climate Center *(http://soildatamart.nrcs.usda.gov/Metadata.aspx?Survey=AK648&UseState=AK)*
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Soils (Chemistry, Erosion, Contaminants, etc.)
Vital Signs: Soil Quality, Land Use and Cover
Summary: This tabular data set contains estimated and measured data on the physical and chemical soil properties, soil interpretations, and static and dynamic metadata. The static tabular metadata documents the underlying data structure, independent of the actual data contained in an export. The static tabular metadata table names are mdstatdomdet, mdstatdommas, mdstatidxdet, mdstatidxmas, mdstatrshipdet, mdstatrshipmas, mdstattabcols, and mdstattabs. The dynamic metadata documents the contents of a particular export. The dynamic metadata table names are distinterpmd, distlegendmd, and distmd. The structure of the static and dynamic metadata tables can be viewed online via the URL listed in the Online_Linkage element above. Most tabular data exist in the database as a range of soil properties, depicting the range for the soil survey area. Data are obtained from a combination of field observations, site descriptions and transects, and laboratory analyses. In making the soil survey,

soil scientists observed landforms and landscape features, such as the steepness, length, and shape of slopes; the general pattern of drainage; the kinds of crops and native plants growing on the soils; and the kinds of bedrock. They observed and studied many soil profiles. Samples of some of the soils in the area were collected for laboratory analyses and for engineering tests. Soil boundaries were drawn on the soil maps and a locally tailored tabular data base was constructed, based on those observations and the resulting landscape model the soil scientist developed. These data can be used with their companion field maps. Contact the U.S. Department of Agriculture, Natural Resources Conservation Service state soil scientist for additional information.

Soils: Kobuk River Basin
National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Soils (Chemistry, Erosion, Contaminants, etc.)
Vital Sign: Soil Quality
Summary: As part of an interagency agreement between the National Park Service (NPS) and the U.S. Geological Survey (USGS), basin characteristics are being determined for a number of watersheds in National Parks of Alaska. Many of the characteristics are being determined by use of Geographical Information Systems (GIS). GIS coverages are being made available to other interested parties.

Spatial patterns of cadmium and lead deposition on and adjacent to National Park Service lands near Red Dog Mine, Alaska
National Park Service
Dataset Type: Non-inventory or monitoring dataset
Ecological Categories: Contaminants, Human Use Activities (Subsistance, Cultural Eutrophication, Mining), Vegetation (general)
Vital Signs: Air Quality, Point-Source Human Effects
Summary: The National Park Service in cooperation with Teck Cominco Alaska Incorporated, the NANA regional corporation, and the Alaska Industrial Development and Export Authority has released the NPS manuscript entitled "Spatial Patterns of Cadmium and Lead Deposition On and Adjacent to National Park Service Lands in the Vicinity of the Red Dog Mine, Alaska" by L. Hasselbach et al. This research identified elevated levels of lead, cadmium and zinc in mosses collected during 2001 from throughout Cape Krusenstern National Monument and adjacent areas. The monument is located to the north of Kotzebue, Alaska. The metals are likely associated with dust from the ore concentrate hauling and storage operations of the Red Dog Mine. The National Park Service is required by law to protect natural and healthy ecosystems. The ecological effects of artificially elevated cadmium and lead levels on the monument are still being assessed; however, the Alaska Department of Health and Social Services Division of Public Health has concluded that the metals found in plants used for subsistence near Red Dog Mine do not pose a public health hazard.

Surficial Deposits of the Kobuk Sand Dunes
National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Windblown Features and Processes (Dunes)
Vital Sign: Geomorphology
Summary: National Park Service dataset. Contains digitized polygons representing geomorphological units and an inventory of dune ridges in Kobuk National Park.

Circumpolar Arctic Vegetation Map
University of Alaska Fairbanks *(http://www.geobotany.uaf.edu/cavm/abstract.html)*
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Vascular Plants
Vital Sign: Land Use and Cover
Summary: The Circumpolar Arctic Vegetation Map (CAVM) shows the types of vegetation that occur across the Arctic, between the ice-covered Arctic Ocean to the north and the northern limit of forests to the south. Environmental and climatic conditions are extreme, with a short growing season and low summer temperatures. The region support plants such as dwarf shrubs, herbs, lichens and mosses, which grow close to the ground. As one moves southward (outward from map's center in all directions), the amount of warmth available for plant growth increases considerably. Warmer summer temperatures cause the size, abundance, and variety of plants to increase. Climate and other environmental controls, such as landscape, topography, soil chemistry, soil moisture, and the available plants that historically colonized an area, also influence the distribution of plant communities.

U.S. Fish & Wildlife Service Wetlands Inventory
US Fish & Wildlife Service *(http://wetlands.fws.gov/)*
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Categories: Land Use/Landcover Change, Wetland (distribution and abundance)
Vital Sign: Water Quality
Summary: The National Wetlands Inventory (NWI) produces and provides information on the characteristics, extent, and status of the nation's wetlands and deepwater habitats and other wildlife habitats.

USGS Alaska Science Center, Water Resources
United States Geological Survey *(http://alaska.usgs.gov/water.html)*
Dataset Type: Long-term monitoring (2+ years)
Ecological Categories: Lake Features & Processes, Stream/River Channel Characteristics & Hydrology, Water Quality/Biota/Chemistry
Vital Sign: Hydrology
Summary: The mission of the U.S. Geological Survey's Water Resources is to provide the hydrologic information and understanding needed for wise use and management of the nation's water resources. For about 100 years, the U.S. Geological Survey has studied the occurrence, quantity, quality, distribution, and movement of the surface and ground water that composes the nation's water resources. As the principal nederal water-data agency, the Geological Survey collects and disseminates about 70 percent of the water data currently being used by numerous state, local, private, and other federal agencies to develop and manage our water resources. This nationwide program, which is carried out through the Water Resources Discipline's 48 water offices and four regional offices, includes the collection, analysis, and dissemination of hydrologic data and water-use information, areal resource appraisals and other interpretive studies, and research projects. Much of this work is a cooperative effort in which planning and financial support are shared by state and local governments and other federal agencies.

USGS Hydrography Dataset
National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Categories: Stream/River Channel Characteristics & Hydrology, Wetland (distribution and abundance)
Vital Sign: Hydrology
Summary: Hydrography data is based on the USGS Digital Line Graph maps (DLG optional format) at a scale of 1:63,360. Minimum mapping unit for polygons is 50 acres. As part of a combined effort between USGS, BLM, and other agencies, the hydrography DLG files have been revised using 1977–85 aerial photography. DLG coverages have been converted to ARC/INFO coverages, and projected to the Alaska Albers projection by the NPS GIS Team. Coverages have been split into polygon and line coverages, depending upon the physical feature.

Wetlands: Kobuk River Basin
National Park Service
Dataset Type: Short-term comprehensive inventory (1 to 2 years)
Ecological Category: Wetland (distribution and abundance)
Vital Sign: Hydrology
Summary: As part of an interagency agreement between the National Park Service and the U.S. Geological Survey, basin characteristics are being determined for a number of watersheds in National Parks of Alaska. Many of the characteristics are being determined by use of Geographical Information Systems. GIS coverages are being made available to other interested parties.

Appendix 7
Summary of Joint Arctic Initiatives of Importance to ARCN

Alaska Satellite Facility
http://www.asf.alaska.edu/index.html

The Alaska Satellite Facility (ASF), located in the Geophysical Institute at the University of Alaska Fairbanks, downlinks, processes, archives, and distributes synthetic aperture radar (SAR) data from the European Space Agency's ERS-1 and ERS-2 satellites, NASA's JERS-1 satellite, and the Canadian Space Agency's RADARSAT-1 satellite.

Available SAR products include full-resolution (25 m) images; low-resolution (240 m) images; complex-format SAR data products that retain amplitude and phase information; geocoded images; and uncorrelated (raw signal) SAR data, representing the original backscattered radar signals. ASF is one of several Distributed Active Archive Centers (DAACs) sponsored by NASA as part of the Earth Observing System initiative.

Arctic Alive! Online Educational Program
http://www.arcus.org/ArcticAlive/index.html

Arctic Alive! is a distance-learning environment for learners to be transported virtually to unique and remote locations within the arctic region. Arctic Alive! is not an information Internet site but an interactive, real-time, and unique web-based education program. It uses a variety of delivery methods and e-learning strategies to deliver arctic research to the classroom.

Arctic Climate Impact Assessment
http://www.acia.uaf.edu/

An international project of the Arctic Council and the International Arctic Science Committee (IASC) to evaluate and synthesize knowledge on climate variability, climate change, and increased ultraviolet radiation and their consequences. The results of the assessment were released at the ACIA International Scientific Symposium held in Reykjavik, Iceland, in November 2004.

Arctic Coastal Dynamics
http://www.awi-potsdam.de/acd/

The Arctic Coastal Dynamics (ACD) program is a multidisciplinary, multinational forum to exchange ideas and information. The overall objective of ACD is to improve our understanding of circum-Arctic coastal dynamics as a function of environmental forcing, coastal geology and cryology, and morphodynamic behavior.

Arctic Environmental Observatory
http://arctic.bio.utk.edu/AEO/

An Arctic Environmental Observatory (AEO) in Bering Strait, funded with support from the National Science Foundation, is a cooperative research project involving scientists Lee Cooper and Jackie

Grebmeier of the University of Tennessee, Gay Sheffield of the Alaska Department of Fish and Game, and Lou Codispoti of the University of Maryland. Additional logistical assistance and support has been provided by the city of Diomede, local residents of Diomede, staff of the Bering Strait School District, and the U.S. and Canadian Coast Guards.

Arctic Logistics Information and Support
http://www.arcus.org/ALIAS/index.html

Arctic Logistics Information and Support (ALIAS) is a primary access point and a comprehensive information source to help researchers to assess the feasibility of working in a specific area; plan the conduct of research; view current research in a given area, including maps and publications; and make useful scientific and logistics support contacts.

Arctic Paleo-River Discharge
http://www.awi-bremerhaven.de/GEO/APARD/

During the Arctic Ocean Science Board (AOSB) meeting held in Helsinki, 17-19 April 1996, it was recognized that freshwater input to and freshwater balance in the Arctic and its (paleo-) environmental significance have been identified as being of high priority to many institutions active in arctic oceanographical, chemical, biological, and geological research. Despite the importance of the Arctic Ocean river discharge on the global climate system and these international projects and programs partly dealing with paleo-river discharge, there is no comprehensive multidisciplinary and international research program on circum-Arctic river discharge and its change through time. Thus, it was decided to convene a series of international, multidisciplinary workshop on Arctic Paleo-River Discharge (APARD). The results of the first APARD Workshop were summarized in a draft and outlined the major scientific objectives and linkages to other international research programs dealing with arctic river discharge. The final APARD program was presented and accepted as an official AOSB program.

Arctic Region Supercomputing Center
http://www.arsc.edu/

The mission of the Arctic Region Supercomputing Center (ARSC) is to support high performance computational research in science and engineering with an emphasis on high latitudes and the Arctic. ARSC provides high performance computational, visualization, networking and data storage resources for researchers within the Department of Defense, the University of Alaska, other academic and scientific institutions, and government agencies.

Arctic Studies Center, National Museum of Natural History, Smithsonian Institution
http://www.mnh.si.edu/arctic/

The Arctic Studies Center, established in 1988, is the only U.S. government program with a special focus on northern cultural research and education. In keeping with this mandate, the Arctic Studies Center specifically studies northern peoples, exploring history, archaeology, social change, and human lifeways across the circumpolar world. The center is part of the Department of Anthropology, in the National Museum of Natural History, a section of the Smithsonian Institution. Having pursued northern studies since the 1850s, the Smithsonian possesses one of the world's finest anthropological collections from arctic and subarctic regions.

Arctic System Science Data Coordination Center
http://arcss.colorado.edu/

The Arctic System Science (ARCSS) Data Coordination Center (ADCC) at the National Snow and Ice Data Center, University of Colorado at Boulder, is the permanent data archive for all components of the ARCSS Program. Funded by the National Science Foundation's Office of Polar Programs, the focus of the center is to archive and provide access to ARCSS-funded data.

Barrow Arctic Science Consortium
http://www.arcticscience.org/

The Barrow Arctic Science Consortium (BASC) is dedicated to the encouragement of research and educational activities pertaining to Alaska's North Slope, the adjacent portions of the Arctic Ocean, and in Chukotka, Russia. A cooperative agreement between BASC and the National Science Foundation's Office of Polar Programs provides funding for BASC's activities.

Bering Climate and Ecosystem
http://www.beringclimate.noaa.gov/

There is an explosion of interest in Northern Hemisphere climate, and new science programs are highlighting the importance of recent changes in the Arctic on mid-latitude climate impacts. The Bering Sea is one of the world's major fisheries, and Alaskan waters provide half of the landed U.S. catch of fish and shellfish. Because of the changes going on in the Arctic, future evolution of the Bering Sea climate/ecosystem is more uncertain. This website presents the current Bering Sea status, a quick data summary, and the main set of time series that form the basis of a smaller set of Bering climate and ecosystem indices.

Center for Global Change and Arctic System Research
http://www.cgc.uaf.edu/

The Center for Global Change is organized under the International Arctic Research Center (IARC) at the University of Alaska Fairbanks (UAF). A board of directors made up of UAF institute directors and deans guides the center's institutional directions and facilitates the cooperation and coordination of the university community. The center has a science steering committee made up of faculty from a wide range of disciplines. This steering committee provides leadership in developing mechanisms to provide and enhance interdisciplinary research and education.

Cooperative Institute for Arctic Research
http://www.cifar.uaf.edu/

The Cooperative Institute for Arctic Research (CIFAR), established in May 1994, promotes research collaboration between the National Oceanic and Atmospheric Administration (NOAA) and the University of Alaska Fairbanks, as well as other agencies and institutions involved in arctic research.

High Latitude Ecosystems Directorate
http://www.mabnet.org/directorates/highlat.html

Special emphasis has been placed on the high-latitude regions of the Earth as potentially responding earliest to effects of global climate change. These regions include the zones of continuous and discontinuous permafrost and some of the most undeveloped land areas of the Northern Hemisphere. They support indigenous human populations that until very recently have practiced a subsistence-based economy and lifestyle. Now these regions are undergoing rapidly accelerating social change, including increased pressure for resource extraction and growing resident populations. These changes have increased scrutiny of resource use and management.

Institute of Arctic and Alpine Research

http://instaar.colorado.edu/

The Institute of Arctic and Alpine Research (INSTAAR) strives for excellence in research, education, and outreach related to Earth system science and global change in high-latitude, alpine, and other environments. INSTAAR is located at the University of Colorado within the graduate school and affiliated with the departments of Anthropology, CEA Engineering, Environmental Studies, Ecology and Evolutionary Biology, Geography, Geological Sciences, and Atmospheric and Oceanic Sciences (PAOS).

International Arctic Science Committee

http://www.iasc.se/

The International Arctic Science Committee (IASC) is a nongovernmental organization whose aim is to encourage and facilitate cooperation in all aspects of arctic research in all countries engaged in arctic research and in all areas of the arctic region.

Long Term Ecological Research

http://www.lternet.edu/

The Long Term Ecological Research (LTER) network is a collaborative effort involving more than 1,800 scientists and students investigating ecological processes over long temporal and broad spatial scales. The network promotes synthesis and comparative research across sites and ecosystems and among other related national and international research programs. The National Science Foundation established the LTER program in 1980 to support research on long-term ecological phenomena in the United States. The 26 LTER sites represent diverse ecosystems and research emphases. The LTER Network Office coordinates communication, network publications, and research-planning activities.

Paleoenvironmental Atlas of Beringia

http://www.ncdc.noaa.gov/paleo/parcs/atlas/beringia/

This World Wide Web site provides historical and geologic information on past climates and environments in Beringia (northwestern North America and northeastern Asia). The site provides basic data (e.g., the original geologic data from individual sites), summaries, and syntheses of the basic data presented in map and/or time-series form. The site is a living scientific document, and syntheses contained within it are synthesized from the data archived in the atlas database. It grows as new data and syntheses become available. The site is intended as a resource for both the global change scientific community and students who wish to learn more about the history of the arctic environment. An additional section for the general public is under construction. See the future directions section for more information about planned sections of the atlas.

Study of Environmental Arctic Change

http://www.arcus.org/SEARCH/index.php

Study of Environmental Arctic Change (SEARCH) is an interagency effort to understand the nature, extent, and future development of the system-scale change presently seen in the Arctic.

U.S. Arctic Research Commission
http://www.arctic.gov/

The United States Arctic Research Commission was established by the Arctic Research and Policy Act of 1984 (as amended, Public Law 101-609). The commission's principal duties are (1) to establish the national policy, priorities, and goals necessary to construct a federal program plan for basic and applied scientific research with respect to the Arctic, including natural resources and materials; physical, biological, and health sciences; and social and behavioral sciences; (2) to promote arctic research, to recommend arctic research policy, and to communicate our research and policy recommendations to the president and Congress; (3) to work with the National Science Foundation as the lead agency responsible for implementing arctic research policy and to support cooperation and collaboration throughout the federal government; (4) to give guidance to the Interagency Arctic Research Policy Committee (IARPC) to develop national arctic research projects and a five-year plan to implement those projects; and (5) to interact with Arctic residents, international arctic research programs and organizations and local institutions, including regional governments in order to obtain the broadest possible view of arctic research needs.

U.S. Man and the Biosphere Program
http://www.mabnet.org/

The U.S. Man and the Biosphere Program (MAB) is an interdisciplinary research effort directed toward providing information for the solution of natural resources and environmental issues. As an intergovernmental program, MAB presents an opportunity for international cooperation and a focus for the coordination of related programs aimed at improving the management of natural resources and the environment.

U.S. National Science Foundation, Office of Polar Programs
http://www.nsf.gov/div/index.jsp?div=ARC

The Office of Polar Programs (OPP) manages and initiates National Science Foundation funding for basic research and its operational support in the Arctic and the Antarctic. The funds are provided as NSF grants to institutions (mainly U.S. universities), whose scientists perform the research at the institutions or in a polar region, and as cooperative agreements or contracts to support organizations, including contractors and the U.S. military.

Appendix 8

Vital Sign Descriptions

Vital Sign: Air Contaminants

Description: This vital sign refers directly to air quality, that is, the presence and concentrations of various pollutants in the air. Air contaminants refers to numerous forms of particulate matter and aerosols such as inorganic carbon, nitrates, sulfates, trace metals, and volatile or semivolatile organic compounds found in the ARCN. Evidence that mercury and persistent organic pollutants are accumulating in arctic environments is of particular concern.

Significance: Contaminants entering the ARCN parks via atmospheric transport can be deposited into the sensitive ecosystems in the parks. Once there, the contaminants can change biochemical cycles and bioaccumulate in the species present in the parks. The contaminants can also degrade visibility in the parks and decrease their scenic beauty. Sensitivity of organisms to air contaminants varies from species to species. Certain species of nonvascular plants (such as lichens and bryophytes), herbaceous flowering plants, algae, fungi, soil arthropods, and terrestrial and aquatic invertebrates are particularly sensitive to a variety of airborne contaminants. In addition, some ecosystems are at higher risk than others. For example, ecosystems with low buffering capacity or areas with high loads of pollution are more susceptible than others. Generally speaking, forest ecosystems, high-altitude environments, freshwater ecosystems, peatlands, heathlands, and areas dominated by lichen cover are highly susceptible to the many forms of air contaminants listed above.

Monitoring Questions:

- Is air quality changing in ARCN Parks?
- What are the main components of air pollution in ARCN parks?

Proposed Metrics: Visibility, particulate matter concentrations (particulate matter less than 2.5 micrometers in diameter, or PM2.5), and concentrations of aerosol components such as inorganic carbon, nitrates, sulfates, trace metals, and volatile organic compounds found in the air. Specifically concerned with nitrates, sulfates, mercury, and persistent organic pollutants.

Specific Methods, Spatial Scale, and Frequency of Measurement: Visual range, particulate matter mass and composition, and volatile organic compound measurements. Continuous sampling of the gaseous and particulate compounds is preferred, but probably not financially feasible. IMPROVE, CASTNet, MDN, and NADP protocols will be sufficient. An additional spatial array of passive samplers is being considered for ARCN.

Current Monitoring: Interagency Arctic Air Quality Site (IMPROVE, CASTNet, MDN, NADP) will be reinstalled in either Bettles or Toolik Lake (near GAAR) with funding from ARD in 2007.

Key References:

Polissar, A., P. Hopke, W. Malm, and J. Sisler. 1998. Atmospheric Aerosol Over Alaska 1. Spatial and Seasonal variability. Journal of Geophysical Research **103**(D15): doi: 10.1029/98JD01365.

Linked Vital Signs: Climate and Weather, Wet and Dry Deposition of Various Pollutants, Point Source Human Effects, Terrestrial Vegetation and Soils, Bird Assemblages, Stream Communities and Ecosystems, Lake Communities and Ecosystems, Lagoon Communities and Ecosystems, and all Mammal vital signs

Vital Sign: Aquatic Invertebrates

(Note: currently integrated with Stream, Lake, and Lagoon Ecosystems vital signs)

Description: Since aquatic invertebrates are short lived, abundant, and less mobile than aquatic vertebrates, they serve as good indicators of aquatic health. While individual species of benthic macroinvertebrates respond rapidly to change, changes in community composition will often reflect larger scale ecosystem changes.

Significance: Aquatic invertebrates are relatively simple to collect and so could be useful in an extensive sampling scheme.

Monitoring Questions:

- Could macroinvertebrates be used as indicators of stream and lake condition?
- How are aquatic invertebrates changing along a longitudinal gradient?
- Are there significant shifts in biodiversity due to warming in the arctic?
- How is the flux of energy, nutrients, and organisms from aquatic to terrestrial ecosystems changing due to the cumulative impacts of global warming?
- What are the long-term changes in riparian communities along river corridors and what is the effect of these changes on stream communities and ecosystem function?
- How will changes in inputs of nutrients affect biota and productivity of lakes? How do changes in the nutrient regime in lakes affect the structure and function of resident biota?
- Are contaminants present in benthic macroarthropods?
- What is the diversity and species composition of benthic arthropods in arctic lakes and streams?

Proposed Metrics: Functional groups, species diversity, abundance, biomass, isotopic ratios

Specific Methods, Spatial Scale, and Frequency of Measurement: Aquatic invertebrates should be sampled when other water-quality parameters are sampled because of the enormous logistics costs of getting to a stream or lake in ARCN. Specific Methods could include implementing indices such as EPA's Rapid Bioassessment protocols, multivariate metrics such as RIVPACS, and collecting organisms to measure level of pollutants. The spatial scale could be extensively throughout the park and intensively at a subset of lakes and streams less frequently.

Current Monitoring: Preliminary biodiversity and landscape classification of aquatic ecosystems in the Noatak Watershed, which includes collection of macroarthropods (ARCN 2005–07).

Key References:

Huryn, A. D., K. A. Slavik, R. L. Lowe, S. M. Parker, D. S. Anderson, and B. J. Peterson. 2005. Landscape Heterogeneity and the Biodiversity of Arctic Stream Communities: A Habitat Template Analysis. Canadian Journal of Fish and Aquatic Sciences 62:1905–1919.

Moss, D., M. T. Furse, J. F. Wright, and P. D. Armitage. 1987. The Prediction of the Macro-Invertebrate Fauna of Unpolluted Running-Water Sites in Great Britain Using Environmental Data. Freshwater Biology 17:41–52.

Oswood, M. W., J. G. Irons III, and A. M. Milner. 1995. River and Stream Ecosystems of Alaska. Pages 9–31 *in* C. E. Cushing, K. W. Cummins, and G. W. Minshall, editors. Ecosystems of the World 22: River and Stream Ecosystems.

Linked Vital Signs: Climate and Weather, Wet and Dry Deposition of Various Pollutants, Point Source Human Effects, Stream Communities and Ecosystems, Lake Communities and Ecosystems, and Lagoon Communities and Ecosystems

Vital Sign: Bird Assemblages

(Note: Workshop planned in FY 2007 to further narrow this vital sign)

Description: Numerous species of birds use ARCN as breeding grounds, of which more than 20 species are of high conservation concern. For many of these species, a major portion of their breeding range lies within ARCN. Most conservation concerns are based on declining population trends and vulnerability of small, geographically restricted populations to environmental disturbances. In some instances, ARCN parks are the most appropriate places to monitor high-concern species because they occur in locally high densities. For example, BELA and CAKR provide breeding habitat for relatively high densities of yellow-billed loons, black scoters, long-tailed ducks, American golden-plovers, whimbrels, bristle-thighed curlews, and bar-tailed godwits. Any changes in status of these populations are likely to be reflected in changes to abundance or distribution on the breeding grounds. Other high-concern species such as gyrfalcons, rough-legged hawks, surfbirds, and Smith's longspurs occur in moderate to high densities throughout most ARCN parks and monitoring their distribution and abundance on a broad scale would be prudent. Also, numerous species of migratory waterfowl and shorebirds use the lagoons and estuary habitats of BELA and CAKR.

Significance: Monitoring bird assemblages is not only important from a population perspective, but breeding and/or migratory bird assemblages may be sensitive indicators of ecosystem change. For example, ptarmigan populations fluctuate in cycles, affecting predator populations, vegetation, and soil dynamics. Furthermore, monitoring particular species assemblages in ARCN could provide the first indications of increasing contaminant loads.

Monitoring Questions:

- What are the temporal trends in breeding phenology, abundance, distribution, and productivity of bird assemblages and species of concern?
- How are temporal changes in breeding phenology, abundance, distribution, and productivity correlated with changes in environmental parameters (e.g., measures of climate, terrestrial and aquatic ecosystems)?
- What are the temporal trends of consumptive use and are there affects on bird populations?
- Are contaminants present in bird assemblages or species of concern?

Proposed Metrics: distribution, abundance, breeding phenology, productivity, numbers harvested, and contaminant loads

Specific Methods, Spatial Scale, and Frequency of Measurement: Conduct aerial breeding pair surveys, multispecies surveys, or annual aerial surveys with simultaneous ground surveys at select staging areas; collect annual harvest information from villages that access ARCN parks; tissue samples for contaminant loads.

Current Monitoring: Yellow-billed loon surveys at BELA and CAKR 2005 by USFWS/ARCN; shorebird inventory in all ARCN parks 2001–2003 by USGS/ARCN; landbird inventory in riparian corridors of GAAR 2003–2006 by GAAR; long-tailed duck and black scoter monitoring in BELA, CAKR and the Selawik NWR by USFWS/ARCN; and the North American waterfowl breeding pair survey, includes areas of BELA and CAKR by USFWS

Key References:

Alaska Shorebird Working Group. 2000. A Conservation Plan for Alaska Shorebirds. Unpubl. rep., available through U.S. Fish and Wildlife Service, Migratory Bird Management, Anchorage, Alaska.

Tibbitts, T. L., D. R. Ruthrauff, R. E. Gill, Jr., and C. M. Handel. 2005. Inventory of Montane-nesting Birds in the Arctic Network of National Parks, Alaska. Arctic Network Inventory and Monitoring Program. National Park Service. Fairbanks, Alaska.

Linked Vital Signs: Air Quality, Climate and Weather, Wet and Dry Deposition of Various Pollutants, Point Source Human Effects, Terrestrial Vegetation and Soils, Stream Communities and Ecosystems, Lake Communities and Ecosystems, Lagoon Communities and Ecosystems, and Surface Water Dynamics and Distribution

Vital Sign: Brown Bears (*Ursus arctos*)

Description: Brown bears are the largest terrestrial carnivore in ARCN. At one time, brown bears roamed over most of the western United States, Alaska, Canada, and southern Mexico. Today, brown bears are found only in parts of Canada, Alaska, Montana, Wyoming, Idaho, and Washington. Brown bears eat a wide variety of foods, including insects, wild honey, roots, grasses, berries, fish, and mammals, and generally reach maturity at five years of age. The average litter size is two, but can be as high as four. Brown bears are particularly sensitive to human development so would be useful indicators of the wilderness character of an area.

Significance: The brown bear is an excellent indicator species because they are an omnivorous top predator, range over large areas (for males, home ranges may exceed 2000 km2), and occur at low population densities. Because brown bears are long lived and have a slow rate of reproduction, they may be particularly sensitive to subtle adverse environmental conditions, and the health of individuals or populations may represent the cumulative effects of various environmental stressors over time. Brown bears are often part of politically sensitive issues within Alaska (e.g., predator control measures).

Monitoring Questions:

- What is the population of brown bears in ARCN?
- Are brown bear distributions changing over time?
- What are the levels of environmental toxins and how are they changing in brown bears?
- How do brown bear populations respond to changes in prey availability?
- How do populations of brown bears vary in relation to human presence and human development in ARCN?

Proposed Metrics: Measure the abundance, presence or absence, and distribution of brown bears in selected areas within the ARCN. Monitor the productivity, recruitment, and adult mortality of brown bears. Measure levels of environmental toxins in brown bear tissues.

Specific Methods, Spatial Scale, and Frequency of Measurement: Aerial direct count surveys of brown bears, use of hunting and sealing records, hair and fecal samples for DNA analysis, mark and recapture models, and radiotelemety studies.

Current Monitoring: ARCN conducted a population abundance survey for brown bears along the central portion of the Noatak River in the spring of 2005 and in BELA in the spring of 2006. Radiotelemetry studies and aerial surveys were conducted near Red Dog mine in the 1980s.

Key References:

Ballard, W. B., L. A. Ayers, K. E. Roney, D. J. Reed, and S. G. Fancy. 1991. Demography of Noatak Brown Bears in Relation to Human Exploitation and Mining Development. Federal Aid in Wildlife Restoration, Final Report W-22-5, W-22-6, W-23-1, W-23-2, and W-23-3, Study 4.20. Alaska Department of Fish and Game, Juneau, AK.

Ballard, W.B. L. A. Ayres, D. J. Reed, S. G. Fancy, and K.E. Roney. 1993. Demography of Brown Bears in Relation to Hunting and Mining Development in Northwestern Alaska. U.S. Department of the Interior, National Park Service Scientific Monograph.

Linked Vital Signs: Air Quality, Climate and Weather, Wet and Dry Deposition of Various Pollutants, Point Source Human Effects, Terrestrial Vegetation and Soils, Stream Communities and Ecosystems, Surface Water Dynamics and Distribution, Subsistence/Harvest, Invasive/Exotic Species, Invasive/Exotic Diseases, Snow and Ice, Fish Assemblages, Caribou, Moose, and Dall's Sheep.

Vital Sign: Caribou (*Rangifer tarandus*)

Description: Caribou are the most common large mammal in ARCN. Caribou from three herds occur in ARCN: (1) Western Arctic Herd (WAH), (2) Central Arctic Herd (CAH), and (3) Teshekpuk Herd (TH). Population parameters and distribution of caribou (Rangifer tarandus) may be good indicators of environmental conditions in both space and time. For example, caribou consume large amounts of lichens and fungi, making them good bio-indicators of environmental toxins.

Significance: With population estimates of approximately 490,000 for the WAH, 45,000 for the TH, and 32,000 for the CAH (Alaska Department of Fish and Game, 2005) caribou are a significant ecological force in northwestern Alaska. Caribou are hunted by both sport and subsistence users of the parks. The presence, absence, and relative abundance of caribou have substantial impacts on the populations of wolves, bears, and wolverines in the area. Caribou are good integrators of conditions in northwest Alaska because of their migratory nature. Caribou populations may have substantial effects on plant and lichen communities and by extension wildlife communities, either directly through browsing and grazing or indirectly through biogeochemical cycling.

Monitoring Questions:

- How is the sex and age composition and relative or absolute abundance of caribou changing over time?
- Migration: Is the timing of migration changing? How are the spatial and temporal patterns of migration changing?
- What is controlling changes in distribution of caribou?
- What are the levels of environmental toxins and how are they changing in caribou?
- How do caribou affect plant and lichen communities? How do ungulates respond to changes in plant and lichen communities?

Proposed Metrics: Possible measures include abundance, presence or absence, and distribution of caribou; trends in population levels; timing of key life history events; timing of migration and seasonal ranges; productivity, recruitment, and adult mortality; evaluation of forage quantity and quality; and monitoring health and body conditions of caribou.

Specific Methods, Spatial Scale, and Frequency of Measurement: Photocensus every three to five years; radiocollaring of animals to track timing of life history events, movement patterns, and to collect information on the health and productivity of individual animals. Forage exclosures, browse transects, and forage use monitoring on grids or transects can be used to evaluate forage quality and quantity. Stable isotopes may be used to examine forage use and physical health on a seasonal and annual basis.

Current Monitoring: The Alaska Department of Fish and Game conducts a photocensus of the western Arctic Caribou herd every three to five years and has radiotelemetry data monitoring adult survival, productivity, and recruitment. The Alaska Department of Fish and Game also has a substantial amount of GPS radiotracking data that could be used to quantify timing of seasonal movements and migrations and the locations of seasonal ranges. A study using stable isotopes is beginning in ARCN in the spring of 2006 to examine body condition in caribou and muskoxen in the late winter.

Key References:

Alaska Department of Fish and Game. 2005. Caribou Management Report of Survey-inventory Activities 1 July 2002–30 June 2004. Edited by C. Brown, Juneau, AK.

Griffith, B., D. C. Douglas, N. E. Walsh, D. D. Young, T. R. McCabe, D. E. Russell, R. G. White, R. D. Cameron, and K. R. Whitten. 2002. The Porcupine Caribou Herd. Pages 8–37 *in* D. C. Douglas, P. E. Reynolds, and E. B. Rhode, editors. Arctic Refuge Coastal Plain Terrestrial Wildlife Research Summaries. U.S. Geological Survey, Biological Resources Division, Biological Science Report USGS/BRD/BSR-2002-0001.

Joly, K., B. W. Dale, W. B. Collins, and L. G. Adams. 2003. Winter habitat use by female caribou in relation to wildland fires in interior Alaska. Canadian Journal of Zoology 81:1192–1201.

Western Arctic Caribou Herd Working Group. 2003. Western Arctic Caribou Herd Cooperative Management Plan. Nome, AK.

Vital Sign: Climate and Weather

Description: Climate is a basic driver of all ecological systems. Basic climate data for most of ARCN is sparse or nonexistent because most climate and weather stations are outside the park boundaries. Climate and precipitation are widely recognized as one of the most fundamental drivers of change. In high latitude regions, snow and ice are dominant features of the landscape for most of the year. Snow and ice heavily influence all ecosystem components in freshwater, coastal, and terrestrial ecosystems. For instance, the extent and degree of ice and snow cover transforms land surfaces, increases surface albedo, and reduces solar energy absorption. Altered albedo over the parks changes the frequency and types of clouds occurring in the region and precipitation frequency. These factors affect solar radiation and precipitation and may ultimately lead to altered duration of the growing season.

Significance: Because climate is a basic driver of all ecological systems, these measurements are important for understanding the relationship between climate and other components of biotic and abiotic systems. Without climate data, it is impossible to understand the causes of a variety of ecosystem changes. Basic climatological measurements lacking for most of ARCN include temperature, cloud cover, precipitation, wind (speed and direction), relative humidity, ice and snow cover, snow depth, and soil temperature.

Monitoring Questions:

- What is the current climate in ARCN?
- What do past and future trajectories of climate change predict in ARCN parks?

Proposed Metrics: Air temperature, cloud cover, precipitation, relative humidity, wind (speed and direction), solar radiation/albedo, storm frequency, soil temperature, and moisture

Specific Methods, Spatial Scale, and Frequency of Measurement: ARCN will install a series of automated weather stations with satellite links throughout the parks. A scoping workshop is planned in early December 2006 to determine criteria for siting weather and climate stations.

Current Monitoring: National Weather Service stations located in communities adjacent to ARCN parklands; RAWS Stations; See map in ARCN draft report (Nolan 2006).

Key References:

Nolan, M. 2006. Scoping Document for Monitoring Climate and Weather in the Arctic National Parklands. National Park Service Report.

Linked Vital Signs: All vital signs are linked to Climate and Weather in ARCN, due to the accelerated rates of climate change in the Arctic.

Vital Sign: Coastal Erosion/Sedimentation/Deposition

Description: The total shoreline in ARCN, including bay and barrier island ecosystems, is approximately 450 km (250 miles). Nearshore coastal waters and shoreline habitats for a range of flora and fauna include subtidal zones, sandy shores, barrier spits and islands, lagoons, bays and inlets, tundra bluffs, dune systems, rocky bluffs, deltas, and wetlands. Coastal change consists primarily of coastal erosion and bluff retreat, as well as less common beach accretion, deposition of sediments during extreme storms, and modification to inlets and lagoons. A particular concern is that coastal ecosystems are changing rapidly with arctic warming and other environmental stressors.

Significance: Coastal and nearshore environments in BELA and CAKR are experiencing dramatic changes, with impacts on a variety of nearshore marine, terrestrial, and freshwater habitats. Coastal erosion directly impacts beach geomorphology and nearshore ecosystems. Erosion of bluffs causes loss of terrestrial habitat. Changes in sediment erosion and deposition can lead to capture of thaw-lake basins, migration of barrier inlets, flooding or closure of inlets, and other modifications to freshwater habitats. Release of sediment and organic carbon alters nutrient fluxes in nearshore marine and lagoon ecosystems. Protected by sea ice for several months each year, the fragile coastal zone may be experiencing accelerated change due to Arctic warming, permafrost melting, sea-level rise, and lengthening of the summer sea-ice free season. Coastal change is one of the most observable and sensitive indicators of environmental change for the Arctic.

Monitoring Questions:

- What is the rate of beach erosion and deposition?
- What processes are driving lagoon formation and stability?
- Are sandy and gravelly shorelines in CAKR and BELA eroding? At what rate?
- What are the hydrodynamic responses of lagoons to beach erosion?
- What is the effect of ice cover change and open ocean season on shoreline ecosystems?
- Will tundra coasts experience accelerated erosion due to thermokarst formation and marine influences (such as sea ice)?

Proposed Metrics: Coastline accretion or erosion; bluff retreat; changes in area, volume, or mass fluxes; changes in nearshore vegetation and landcover.

Specific Methods, Spatial Scale, and Frequency of Measurement: Remote sensing with satellite imagery, orthorectified aerial photography, and digital elevation models; field mapping and measurements; repeat ground and aerial photography and videography. Scale of measurement is dependent on rates of change, but generally requires high resolution (1 m or better). Coastal change should be quantified approximately every five years, with additional observations during or after large storm events.

Current Monitoring: ARCN Inventory and Monitoring of Coastal Erosion for Alaska's Arctic Network of Parks by William Manley (University of Colorado, Boulder); long-term coastal erosion/accretion plots in BELA and CAKR by James Jordan and Owen Mason (Antioch University).

Key References:

Jorgenson, M. T., and J. Brown. 2005. Classification of the Alaskan Beaufort Sea Coast and estimation of carbon and sediment inputs from coastal erosion: Geomarine Letters 25:69–80.

Rachold, V., H. Lantuit, N. Couture, and W. H. Pollard, eds. 2005. Arctic Coastal Dynamics: Report of the Fifth International Workshop, McGill University, Montreal, Canada: Rep. Polar and Marine Research, v. 505.

Linked Vital Signs: Climate and Weather, Snow and Ice, Point Source Human Effects, Terrestrial Vegetation and Soils, Bird Assemblages, Stream Communities and Ecosystems, Lake Communities and Ecosystems, Lagoon Communities and Ecosystems, Surface Water Dynamics and Distribution, and Sea Ice

Vital Sign: Dall's Sheep (*Ovis dalli*)

Description: Dall's sheep occur throughout the alpine areas of the ARCN. Relative to some of the other large mammals in the ARCN, Dall's sheep are relatively stationary. Population parameters and distribution of Dall's sheep may be good indicators of environmental conditions in alpine areas of ARCN.

Significance: Dall's sheep reach the northernmost extent of their range in the Brooks Range. For park visitors, they are the most reliably viewed large mammal within the parks because they do not migrate and they are far more numerous than moose, wolves, bears, or muskoxen. Dall's sheep can be legally hunted in ARCN parks by qualified subsistence users, and sport hunting for sheep is permitted in the preserve portion of Gates of the Arctic and in the Noatak Preserve. Singer (1984) estimated the Dall's sheep population in the units to be approximately 15,000 animals. Given a rough estimate of 100,000 Dall's sheep worldwide (Valdez and Krausman 1999), ARCN harbors a large percentage of the world's population of Dall's sheep.

Monitoring Questions:

- How is the sex and age composition and relative or absolute abundance of Dall's sheep populations changing over time?
- Is the distribution of Dall's sheep changing?
- What is the population size of Dall's sheep?
- What are the levels of environmental toxins in Dall's sheep and how are they changing?
- How do Dall's sheep affect plant communities in the ARCN network? How do Dall's sheep respond to changes in plant communities?
- What are the spatial and temporal patterns of life-history events (e.g., rut, calving, seasonal movements) of Dall's sheep in ARCN?
- What are some of the key environmental/weather factors that dictate distribution and productivity of Dall's sheep in ARCN?
- How do Dall's sheep interact with brown bears (Ursus arctos), wolves (Canis lupus), and wolverines (Gulo gulo) in ARCN and what effects do these predators have on Dall's sheep populations?

Proposed Metrics: Measures include abundance, presence or absence, and distribution; productivity, recruitment, and adult mortality; sex and age distribution; and health and body conditions of Dall's sheep in selected areas within the ARCN.

Specific Methods, Spatial Scale, and Frequency of Measurement: Aerial direct count surveys every three years. Ground-based lambing surveys may be feasible in some areas of high sheep density. Radiocollar studies can be used to track timing of life history events and movement patterns and to collect information on health and productivity of individual animals. Forage exclosures and forage use monitoring on grids or transects can be used to evaluate forage quality and quantity.

Current Monitoring: An aerial survey that covered all of ARCN was completed in 1983. In the eastern portion of ARCN, Dall's sheep surveys were conducted by the NPS near the community of Anaktuvuk Pass from 1998 to 2002. Also in the eastern portion of ARCN, a survey was completed near the community of Anaktuvuk Pass and in the Itkillik Preserve in 1996. In the western portion of ARCN, sheep surveys have been completed annually in the Baird and Delong mountains. ARCN began a sheep survey in 2005.

Key References:

Brubaker, R., and K. Whitten. 1998. Dall sheep (Ovis dalli dalli) survey, Gates of the Arctic National Park and Preserve, Alaska. Tech. Rep. NPS/AR/NRTR-98/35. National Park Service, Fairbanks, AK.

Kleckner, C., L. G. Adams, B. Shults, and M. S. Udevitz. 2002. Abundance and Demography of Dall Sheep in the Baird Mountains, Noatak National Preserve, Alaska; Component: Population Demographics. Annual Progress Report, Alaska Biological Science Center, U.S. Geological Survey, Anchorage, AK.

Lawler, J. P. 2004. Demography and Home Ranges of Dall's sheep in the Central Brooks Range, Anaktuvuk Pass, Alaska. National Park Service,Technical Report NPS/AR/NRTR-2004-43.

Singer, F. J. 1984. Aerial Dall's Sheep Count, 1982, 1983, 1984, Gates of the Arctic National Park and Preserve. United States National Park Service, Alaska Region, Natural Resource Survey and Inventory Report, Anchorage AK.

Singer, F. J. 1983. Dall Sheep Numbers and Distribution in the Noatak National Preserve, 1983. National Park Service, Alaska Region, Natural Resource Survey and Inventory Report, Anchorage, AK.

Valdez, R. and P. R. Krausman. 1999. Description, distribution and abundance of mountain sheep in North America. Pages 3–22 *in* R. Valdez and P. R. Krausman, editors. Mountain Sheep of North America. University of Arizona Press, Tucson, AZ.

Linked Vital Signs: Climate and Weather, Terrestrial Vegetation and Soils, Subsistence/Harvest, Invasive/Exotic Species, Invasive/Exotic Species Diseases, Snow and Ice

Vital Sign: Fire Extent and Severity

Description: Climate, terrain and vegetation strongly influence the occurrence and extent of fires within ARCN. Wildland fire is one of the largest natural disturbance processes in the boreal and tundra ecosystems of ARCN. Fire affects all of the parks within ARCN; in the past 50 yrs over 1 million acres have burned in the network. Fire influences not only vegetation succession and distribution, but also wildlife habitat, soil parameters (e.g., permafrost and nutrient cycling), hydrology, water quality and air quality. The natural fire regime is likely to respond to local and global climate changes. Baseline monitoring of fire parameters such as the number of fires, fire extent, and burn severity will provide explanatory variables for ecological changes detected through the I&M program, while long-term monitoring of fire effects on vegetation will provide a foundation to elucidate the complex relationship between fire and the landscape.

Significance: Current and future climatic changes will impact the occurrence, extent, and severity of fires in the ARCN and will have cascading effects on other ecosystem processes. Fire can exert strong landscape-scale effects on vegetation composition and distribution, permafrost dynamics, nutrient cycling, carbon gain or loss, and primary productivity.

Monitoring Questions:

- What is the distribution of vegetation across the landscape and how is it changing?
- What are the long-term trends and natural level of variation in the frequency, extent, and burn severity of fires? Is there a pattern between global climate change and frequency, extent, and burn severity of fires?
- How do shifts in human-caused perturbations (e.g., human-induced climate change, fire start, fire suppression) affect biodiversity and native species?
- How do the time since the fire and the burn severity affect the species composition, vegetation structure, and ground cover among varying vegetation types?
- How do the time since the fire and the burn severity affect soil parameters (soil temperature, soil moisture, depth of active layer, permafrost, thermokarst development), water quality and air quality?
- How do the time since the fire and the burn severity affect the abundance, distribution and composition of the wildlife populations (i.e., moose, caribou, small mammals, birds)?

Proposed Metrics: post-fire revegetation and succession; nutrient cycling and active layer response, burn severity, fire extent, and fire frequency

Specific Methods, Spatial Scale, and Frequency of Measurement: Burn severity mapping could be accomplished using Landsat imagery. Burn severity maps are produced by applying the Differenced Normalized Burn Ratio (ΔNBR) to before and after fire Landsat imagery. Fire location and extent will be collected for all fires occurring within ARCN parks each year. Extent of fire perimeters can be measured by physical mapping (GPS) or with remote sensing platforms such as Landsat 7 or MODIS.

Current Monitoring: Quantifying the Thermal and Permafrost Impacts of a Tundra Wildfire by Larry Hinzman (UAF), NSF Grant near Quartz Creek (just outside of BELA). Charles Racine and Jennifer Allen looked at permanent fire effects plots in NOAT and BELA in 2006. NPS Fire Management Office is doing burn severity, fire extent, and location mapping in ARCN parks. NPS Fire Management also has six permanent fire effects plots in the NOAT from the 2004 fires.

Key References:

Kasischke, E. S., D. Williams, and D. Barry. 2002. Analysis of the patterns of large fires in the boreal forest region of Alaska. International Journal of Wildland Fire 11:131–144.

Racine, C., R. Jandt, C. Meyers, and J. Dennis. 2004. Tundra Fire and Vegetation Change along a Hillslope in the Seward Peninsula, AK, USA. Arctic, Antarctic, and Alpine Research **36**:1–10.

Rupp, T. S., F. S. I. Chapin, and A. M. Starfield. 2000. Response of subarctic vegetation to transent climatic change on the Seward Peninsula in north-west Alaska. Global Change Biology **6**:541–555.

Linked Vital Signs: Climate and Weather, Terrestrial Vegetation and Soils, Snow and Ice, Surface Water Dynamics and Distribution, Permafrost and Thermokarsting, Invasive/Exotic Species, Terrestrial Landscape Patterns and Dynamics

Vital Sign: Fish Assemblages

Description: There are 27 species of freshwater and anadromous fish known to occur in ARCN (see Chapter 1 of this report). Fish assemblages may be good integrators of long-term landscape-scale change because they are long-lived and relatively mobile. Fish assemblages in ARCN include species at a variety of trophic levels with different life history characteristics. Fish occupying higher trophic levels such as insectivores, piscivores, and omnivores could be useful in assessing changes in contaminant loads. The return of anadromous salmon to fresh water brings marine-derived nutrients and may contribute to shifts in riparian or landscape-scale vegetation or soil patterns.

Significance: Freshwater and anadromous fish are very important as a subsistence resource to the residents of the ARCN. They are also important to park visitors who may be attracted to some parks because of the quality of sport fishing or unique species available. The health of freshwater fish populations may serve as a measure of freshwater ecosystem condition.

Monitoring Questions:

- What is the current status of fish populations in ARCN freshwater ecosystems?
- How is consumptive use of fish impacting aquatic ecosystems?
- Is the range of key species expanding with climate change?

Proposed Metrics: Species composition, biodiversity, range, length, weight, sex, and relative abundance in selected freshwater drainages.

Specific Methods, Spatial Scale, and Frequency of Measurement: Periodic surveys of fish to determine presence or absence could be done. Historical fish data collected by ADF&G from in and around the parks (dating back to the early 1980s) could be used for comparative purposes.

Current Monitoring: Chum salmon test fishing in the Kobuk River (ADF&G) and aerial surveys of chum salmon spawners in the Kobuk River (ADF&G). There is some historical aerial survey data for Dolly Varden.

Key References: See current ARCN database on fishes in ARCN at http://www1.nature.nps.gov/im/units/arcn/products_index.cfm

Linked Vital Signs: Air Quality, Climate and Weather, Wet and Dry Deposition of Various Pollutants, Point Source Human Effects, Lake Communities and Ecosystems, Stream Communities and Ecosystems, Lagoon Communities and Ecosystems, Surface Water Dynamics and Distribution, Subsistence/Harvest, Invasive/Exotic Species, Invasive/Exotic Diseases, and Snow and Ice

Vital Sign: Invasive/Exotic Species and Diseases

Description: Invasive and/or exotic plant or animal species and diseases may be a concern in ARCN. Potential pathways are road corridors, river corridors, ATV trails, aircraft landings, migratory species, pack animals, pets, animal feed, and visitor use.

Significance: Invasive species often possess reproductive characteristics that allow them to compete with and dominate native species. They tend to have short reproductive cycles and produce prolific offspring. Exotic species often lack predators, which further enables them to out compete and or dominate local populations. For plants in many cases, these characteristics allow exotic species to eventually form monocultures.

Monitoring Questions:

- What exotic species are present and have established populations in the ARCN?
- What native species are being harmed or displaced by exotic species?

Proposed Metrics: Presence or absence, abundance, and distribution of exotic species

Specific Methods, Spatial Scale, and Frequency of Measurement: Monitoring methods for invasive and/or exotic species and diseases need to be decided by each linked group; many protocols are already developed by other groups monitoring various species. ARCN could monitor high-risk areas along road corridors, villages, access points, and heavily traveled transportation routes (airstrips, navigable waters, etc.). For animal disease, blood and tissue samples of captured or killed animals.

Current Monitoring: Committee for Noxious and Invasive Plants Management in Alaska; the Alaska Department of Fish and Game has produced an Aquatic Nuisance Species Management Plan. The state veterinarian for the Alaska Department of Fish and Game has a collection of blood and tissue samples from which to determine background levels of disease in wildlife species.

Linked Vital Signs: Climate and Weather, Point Source Human Effects, Terrestrial Vegetation and Soils, Stream Communities and Ecosystems, Subsistence/Harvest, Fish Assemblages, Bird Assemblages, Caribou, Moose, Brown Bears, and Dall's Sheep

Vital Sign: Lagoon Communities and Ecosystems

Description: The total shoreline in ARCN, including bay and barrier island ecosystems, is approximately 450 km (250 miles). This is the third largest block of coastline that NPS manages. There is very little baseline information on the coastal lagoon communities of BELA and CAKR. There are five large coastal lagoons in CAKR and three in BELA.

Significance: Due to changes in sea ice and arctic coastal dynamics (especially coastal erosion), lagoon ecosystems of CAKR and BELA could experience drastic changes.

Monitoring Questions:

- What are the annual parameters of ice and snow cover in lagoons?
- What is the species composition and relative abundance of biota in lagoons and estuaries?
- What are the sources and levels of contaminants in lagoon ecosystems?
- What changes in water chemistry are occurring in lagoon ecosystems? How are changes in water chemistry influencing primary productivity?
- How do shifts in human-caused perturbations affect biodiversity and native species composition in the lagoons?
- How is climate change altering biodiversity and species distribution in ARCN lagoons?

Proposed Metrics: All water quality parameters (see Water Quality vital sign for more details), macrophyte diversity and distribution; algae diversity and biomass (chlorophyll A); zooplankton diversity and composition; benthic invertebrate composition; fish diversity and composition; secchi depth; thermal structure; stratification; light penetration; extent of littoral zone; bathymetry where possible; change in lagoon area and extent (see Surface Water Dynamics and Distribution vital sign for more information)

Specific Methods, Spatial Scale, and Frequency of Measurement: extensive measurements of physical, chemical, and biological and parameters in coastal lagoons

Current Monitoring: None

Linked Vital Signs: Stream Communities and Ecosystems, Lake Communities and Ecosystems, Weather and Climate, Snow and Ice, Rare Communities/Habitats/Ecosystems, Air Contaminants, Wet and Dry Deposition of Various Pollutants, Terrestrial Vegetation and Soils

Vital Sign: Lake Communities and Ecosystems

Description: The ARCN contains a diverse array of lake ecosystems, including maar lakes, high alpine lakes, cirque lakes, thousands of small shallow lakes, and a small suite of large pristine lakes. Little is currently known about the ecosystem dynamics of the various lakes in the Arctic. Because little is known about ARCN ecosystems and logistics are prohibitively complex, ARCN plans to take a ecosystem approach to monitoring lake ecosystems. The benefit of this approach is that it will provide ARCN with basic knowledge regarding the entire system and all its components. Maximizing the information obtained during a site visit is particularly important in ARCN parks because access to these extremely remote areas is complex and costly.

Significance: Lakes are excellent integrators of terrestrial ecosystems. Understanding changes in the physical, chemical, and biological attributes of lakes can provide clues to processes occurring in the watershed as well as the lake basin itself.

Monitoring Questions:

- Are contaminants present in lake ecosystems and in what ecosystem compartment (biotic or abiotic)?
- How will expected climate change affect lake ecosystems?
- How are the physical and chemical constituents of lake ecosystems changing?
- How is the distribution and species composition of zooplankton, macroinvertebrates, and fish in ARCN lakes changing?
- How do shifts in human-caused perturbations affect biodiversity and native species in lake ecosystems?

Proposed Metrics: All water quality parameters (see Water Quality vital sign for more details), macrophyte diversity and distribution, algae diversity and biomass (chlorophyll A), zooplankton diversity and composition, benthic invertebrate composition, fish diversity and composition, secchi depth, thermal structure, stratification, light penetration, extent of littoral zone, bathymetry where possible, lake area and extent (see Surface Water Dynamics and Distribution vital sign for more information)

Specific Methods, Spatial Scale, and Frequency of Measurement: extensive measurements of physical, chemical, and biological parameters in many lakes. Periodically every five to 10 years.

Current Monitoring: ARCN Freshwater Initiative of the Noatak National Preserve; NSF-funded studies at the Toolik Lake Long-term Ecological Research site

Linked Vital Signs: Stream Communities and Ecosystems, Lagoon Communities and Ecosystems, Weather and Climate, Snow and Ice, Rare Communities/Habitats/Ecosystems, Air Contaminants, Wet and Dry Deposition of Various Pollutants, Terrestrial Vegetation and Soils

Vital Sign: Moose (*Alces alces*)

Description: Moose occur throughout the boreal forests of the ARCN. Moose are an important subsistence resource in ARCN. Population parameters and distribution of moose may be good indicators of environmental conditions in both time and space.

Significance: Moose are a heavily used subsistence resource in the ARCN and are currently being surveyed by park resource staff on a yearly basis. Moose could have substantial impacts on vegetation and nutrient cycling in riparian areas.

Monitoring Questions:

- How is the sex and age composition and relative or absolute abundance of moose populations changing over time?
- Is the distribution of moose changing?
- What are the levels of environmental toxins in moose and how are they changing?
- How do moose affect plant communities in ARCN? How do moose respond to changes in plant communities?
- What are the spatial and temporal patterns of life-history events (e.g., rut, calving, seasonal movements) of moose in ARCN?

Proposed Metrics: Measure the abundance, presence or absence, and distribution of moose; monitor timing of key life history events in moose; monitor the productivity, recruitment, and adult mortality of moose; monitor sex and age distribution of moose; monitor and evaluate forage quantity and quality; monitor health and body conditions of moose.

Specific Methods, Spatial Scale, and Frequency of Measurement: Aerial direct count surveys, radio-collar studies, forage exclosures, and forage use monitoring on grids or transects.

Current Monitoring: Aerial surveys have been conducted in the primary moose ranges in ARCN but the frequency of these surveys has varied substantially.

Key References:

Franzmann, F., and C. C. Schwartz. 1997. Ecology and Management of the North American Moose. Wildlife Management Institute. Smithsonian Institution Press, Washington, DC.

Gasaway, W. C., R. D. Boertje, D. V. Grandgard, K. G. Kellyhouse, R. O. Stephenson, and D. G. Larsen. 1992. The Role of Predation in Limiting Moose at Low Densities in Alaska and the Yukon and Implications for Conservation. Wildl. Monogr. 120.

Gasaway, W. C., S.D. DuBois, D. J. Reed, and S. J. Harbo. 1986. Estimating Moose Population Parameters from Aerial Surveys. Biol. Pap. 22. University of Alaska.

Linked Vital Signs: Terrestrial Vegetation and Soils, Subsistence/Harvest, Invasive/Exotic species and Diseases, Snow and Ice, Climate and Weather, Wet and Dry Deposition of Pollutants, and Air Quality

Vital Sign: Muskoxen (*Ovibos moschatus*)

Description: By the middle of the 19th century, muskoxen were extirpated from Alaska (Lent 1999). Muskoxen were re-established in Alaska in the 1930s. Currently, viable muskoxen populations occur in four locations in Alaska; two of these ranges overlay park units in ARCN. Population parameters and distribution of muskoxen may be good indicators of environmental conditions in both time and space.

Significance: Muskoxen were re-established on the Seward Peninsula and near Cape Krusenstern in the 1970s. Since their establishment, muskoxen have become an important subsistence food for local residents and are highly prized for sport hunting. Muskoxen tend to occupy small areas in comparison to migratory species such as caribou, so they are good integrators for local environmental conditions. Muskox populations may have substantial effects on plant communities either directly through browsing and grazing or indirectly through biogeochemical cycles. Muskoxen are rare worldwide. Within the U.S. national park system, muskoxen only occur in the ARCN.

Monitoring Questions:

- How is the sex and age composition and relative or absolute abundance of muskoxen populations changing over time?
- What are the levels of environmental toxins in muskoxen and how are they changing?
- How do muskoxen affect plant communities in ARCN? How do muskoxen respond to changes in plant communities?
- What are the spatial and temporal patterns of life-history events (e.g., rut, calving, seasonal movements) of muskoxen in ARCN?

Proposed Metrics: Measure the abundance, presence or absence, and distribution; document trends in population levels; monitor timing of key life history events; monitor the productivity, recruitment, and adult mortality; monitor sex and age distribution; monitor and evaluate forage quantity and quality; and monitor health and body conditions of muskoxen.

Specific Methods, Spatial Scale, and Frequency of Measurement: Aerial direct count surveys, radio-collar studies, forage exclosures, browse transects, forage use monitoring on grids or transects, stable isotope analysis

Current Monitoring: NPS has routinely conducted population abundance surveys for muskoxen in the ARCN, and these surveys have typically been done in cooperation with other federal and state natural resource agencies. Muskoxen population surveys and sex and age composition surveys are completed annually in Cape Krusenstern National Monument, every three years in Bering Land Bridge National Preserve, and periodically in Gates of the Arctic National Park and Preserve. The NPS and the Institute of Arctic Biology (University of Alaska Fairbanks) initiated a study in the spring of 2006 to examine body condition of muskoxen in the late winter in ARCN using stable isotopes. NPS monitoring of winter range condition and classification in BELA.

Key References:

Lent, P. 1999. Alaska's Indigenous Muskoxen: A History. Rangifer **18**:3–4.

Nellemann, C. 1998. Habitat Use by Muskoxen (*Ovibos Moschatus*) in Winter in an Alpine Environment. Can. J. Zool. **76**:110–116.

Reynolds, P. E. 1998. Dynamics and Range Expansion of a Reestablished Muskox Population. Journal of Wildlife Management **62**(2):734–744.

Smith, T. 1989. The Status of Muskoxen in Alaska. *In* D. R. Klein, R. G. White, and S. Keller, editors. Proceedings of the First International Muskox Symposium. Biological papers of the University of Alaska, Special Report No. 4.

Linked Vital Signs: Terrestrial Vegetation and Soils, Subsistence/Harvest, Invasive/Exotic Species and Diseases, Snow and Ice, Climate and Weather

Vital Sign: Permafrost, Peatland Soils, and Thermokarsting/Solifluction

Description: Air temperatures are increasing in ARCN, and most of the area is underlain by permafrost. Higher ambient temperatures will increase soil active-layer depth and decrease permafrost presence in arctic and subarctic regions. This anticipated change in permafrost dynamics will have broad impacts on regional hydrology, peatland soils, biogeochemistry, and vegetation patterns and therefore on large-scale ecosystem structure and function. Thermokarst could lead to altered soil nutrient dynamics in ARCN parklands with their extensive, and largely icebound, soil organic matter reservoirs (peatlands). Thermokarst will likely have significant effects on carbon sequestration in wetter areas, and loss of permafrost may cause drier, more aerobic soil conditions in upland areas. Monitoring changes in permafrost presence (and depth to permafrost) would provide a simple indicator of interactions between climate and soil.

Significance: Changes in permafrost will have large effects on hydrology, water quality, soils, vegetation, and trace gas emissions.

Monitoring Questions:

- Are there spatial and temporal changes in permafrost? Is widespread thermokarsting occurring?
- What are the impacts of melting permafrost on nutrient cycling and element transport to aquatic ecosystems
- Is the extent and distribution of thermokarsts increasing due to warming in the Arctic?
- How are changes in permafrost and increased thawing due to warming and related changes in precipitation affecting hydrologic networks in ARCN?
- Is permafrost degrading in ARCN in response to changing climatic conditions?

Proposed Metrics: Deep borehole temperatures, temperatures of ground surface and permafrost table, surface topography, amount of thaw settlement, active-layer depths, groundwater depths, organic thickness accumulation, total extent of thermokarst using remote sensing, total extent of differing types of thermokarst, and lateral rates of thermokarst, time since fire

Specific Methods, Spatial Scale, and Frequency of Measurement: A permafrost monitoring network would involve five types of efforts: (1) deep permafrost temperatures would be measured at a few regionally representative sites each year; (2) field monitoring of shallow ground temperatures, surface topography, thaw depths, and groundwater depths would be measured at a network of approximately 10 monitoring transects every three years; (3) baseline ground ice and carbon stratigraphy would be measured at three to five cores per transect; (4) remote sensing would use high-resolution imagery at the monitoring sites to measure total extent of thermokarst, total extent of differing types of thermokarst, and lateral rates of thermokarst every 10 years; and (5) high-resolution aerial photographs would be acquired at 300 to 500 points across ARCN to quantify extent and type of permafrost degradation every 10 years.

Current Monitoring: ARCN baseline study of thermokarsting in the Noatak Basin (2006).

Key References:

Brown, J., K. M. Hinkel, and F. E. Nelson. 2000. The Circumpolar Active Layer Monitoring (CALM) Program: Research Designs and Initial Results. Polar Geography 24:165–258.

Jorgenson, M. T., C. H. Racine, J. C. Walters, and T. E. Osterkamp. 2001. Permafrost Degradation and Ecological Changes Associated with a Warming Climate in Central Alaska. Climatic Change 48:551–579.

Jorgenson, M. T., Y. L. Shur, and E. R. Pullman. 2006. Abrupt Increase in Permafrost Degradation in Arctic Alaska. Geophys. Res. Lett. 33. L02503, doi:10.1029/2005GL024960

Karle, K. F. and M. T. Jorgenson. 2004. Review of Existing Permafrost Monitoring Projects With Application and Recommendations for the Central Alaska Network Ecological Monitoring Program. Unpublished report prepared for National Park Service, Fairbanks, Alaska, by Hydraulic Mapping and Modeling, Denali Park, Alaska, and ABR, Inc., Fairbanks, Alaska.

Osterkamp, T. E., and A. H. Lachenbruch. 1990. Thermal Regime of Permafrost in Alaska and Predicted Global Warming. Journal of Cold Regions Engineering 4:38-42.

Linked Vital Signs: Stream Communities and Ecosystems, Lagoon Communities and Ecosystems, Lake Communities and Ecosystems, Weather and Climate, Snow and Ice, Terrestrial Vegetation and Soils, Coastal Erosion, Surface Water Dynamics and Distribution

Vital Sign: Small Mammal Assemblages

Description: Population parameters and distribution of small mammals in the ARCN may be good indicators of both short-term and long-term environmental conditions. Small mammals are good indicators of environmental toxins.

Significance: Population levels of small mammals and fluctuations of these populations could have effects on plant, bird, and mammal communities in boreal and alpine/arctic areas.

Monitoring Questions:

- How is the relative abundance of small mammals changing over time?
- What are the spatial and temporal patterns of small mammal abundance?
- What are the level of environmental toxins in selected small mammal species?
- How is the species richness of small mammals changing over time and space?

Proposed Metrics: Measure the abundance, presence or absence, and distribution of small mammals. Monitor environmental toxins in small mammals in selected areas.

Specific Methods, Spatial Scale, and Frequency of Measurement: Mark and recapture studies using transects or grids.

Current Monitoring: ARCN small mammal inventory completed (Cook and MacDonald 2006), see reference below.

Key References:

Cook, J. A., and S. O. MacDonald. 2004. Mammal Inventory of Alaska's National Parks and Preserves: Arctic Network: Bering Land Bridge NP, Cape Krusenstern NM, Kobuk Valley NP, Noatak NP, and Gates of the Arctic NP&P. National Park Service Alaska Region, Inventory and Monitoring Program Final Report 2004.

Swanson, S. A. 1996. Small Mammal Populations in Post-Fire Black Spruce (*Picea Mariana*) Seral Communities in the Upper Kobuk River Valley, Alaska. National Park Service Technical Report NPS/AFARBR/NRTR-96/30.

Linked Vital Signs: Terrestrial Vegetation and Soils, Snow and Ice, Climate and Weather, Wet and Dry Deposition of Various Pollutants, and Air Contaminants

Vital Sign: Surface Water Dynamics and Distribution

Description: Surface water dynamics refers to the characteristics of flowing (lotic) systems. Surface water distribution refers to still water (lentic) characteristics. Arctic surface water dynamics and distribution respond directly to atmospheric processes, glacial mass balance, permafrost melting, and groundwater inputs and are influenced by characteristics of local topography, runoff pathways, and watershed drainage networks.

Significance: Much of the physical and biological makeup of ARCN is dictated by the interactions of hydrology and permafrost. Stream flow regimes and patterns are influenced by thermokarst, aufice, freezing, thawing, flooding, drying, and draining as the landscape responds to local and global climatic cycles. Climatic changes are predicted to occur first and be most severe in arctic regions, particularly with permafrost being such a strong driver of hydrological patterns. Water discharge and soil hydrology are all affected by underlying soil characteristics, and each of these in turn could have a profound influence on landscape-level dynamics of terrestrial vegetation.

Monitoring Questions:

- Are the volume and distribution patterns of standing water changing?
- How is water quantity and distribution of water bodies changing?
- How is changing land cover affecting the distribution and characteristics of water resources?
- How are hydrologic regimes changing? Are streams and floodplain interactions changing?
- Is flood frequency and extent changing?
- Is the extent and distribution of thermokarsts increasing due to waming in the Arctic?
- How are changes in permafrost and increased thawing (due to warming and related changes in precipitation) affecting hydrologic networks in ARCN?

Proposed Metrics: Change in river discharge, formation of water tracks and new streams, change in lake distribution and area, change in mass water balance

Specific Methods, Spatial Scale, and Frequency of Measurement: Discharge could be quantified inexpensively and unobtrusively by installing recording stage gauges (e.g., pressure transducers or capacitance probes) that could be set up to record unattended over most for the free-flowing season, from early June to late August. Ideally these dataloggers would be powered to allow telemetry that would verify in real time that the units are working. Distribution: Remote sensing using some combination of multispectral and SAR imagery could effectively identify the distribution of water across the land. Specific monitoring 'scenes' could be set up for routine monitoring. Pattern recognition software (e.g., e-Cognition) could be trained to identify lakes, ponds, and even rivers. Change analysis over time could be used to monitor landscape-scale dynamics. Reanalysis of monitoring scenes would not need to be done more frequently than once every five years.

Current Monitoring: None

Linked Vital Signs: Weather and Climate, Snow and ice, Lake Communities and Ecosystems, Stream Communities and Ecosystems, Permafrost and Thermokarsting

Vital Sign: Terrestrial Landscape Patterns and Dynamics

Description: This vital sign refers to the overall changes in terrestrial landscape patterns, heterogeneity and dynamics. Landscape dynamics in ARCN are heavily driven by cold temperatures and arid conditions. The dynamics of perennially frozen soils affect nearly all aspects of the arctic ecosystem. Important influences include: permafrost distribution, biogeochemical cycling, snowpack persistence, vegetation changes, ice dynamics, changes in lake/pond levels, slope and riverbank slumping, active-layer thickness, solifluction, changes in channel morphology, distribution of waterbodies and habitat fragmentation. Remote Sensing and landcover mapping may be used, for example, to assess changes in the extent of boreal forest and shrub-dominated ecosystems, loss of heathlands and lichen barrens, waterbody extent, lake drying and creation.

Significance: Landcover classification is one of the cost effective methods to assess status and trends in vegetation in ARCN's 19.1 million acres of remote, roadless areas. Changes in plant production in the vast area encompassed by ARCN parklands may have an impact every component of associated foodwebs, including humans. Current and future climatic changes will impact vegetation in the network. This will have cascading effects on other ecosystem processes, such as permafrost dynamics, nutrient cycling, carbon gain or loss, and primary productivity.

Monitoring Questions:

- What is the distribution of vegetation across the landscape and how is it changing?
- How are changes in land cover and terrestrial vegetation composition affecting aquatic ecosystems and the distribution and characteristics of water resources?
- What are the cumulative effects of fragmentation and its effect on population migrations?
- How is ARCN biodiversity affected by landscape-level changes in habitat type and distribution?
- Is treeline advancing North? How is shrubline changing?

Proposed Metrics: Biomass and phenology (NDVI), primary productivity. Total and percent area of each land cover class

Specific Methods, Spatial Scale, and Frequency of Measurement: Biomass and greening could be measured by using an NDVI index. Annual metric will be peak NDVI, date of greenup, date of senescence, total days of greenness, beginning and end of snow melt, date of first total snow cover. The analysis will be done yearly, based on near-daily images.

Landscape-scale changes in primary productivity—long-term landscape scale shifts in primary productivity may be monitored by using AVHRR (Advanced Very High Resolution Radiometer) and MODIS (Moderate Resolution Imaging Spectroradiometer sensors) in combination with aerial photography. Recommend ongoing monitoring of areas that have been the sites of ongoing repeat photography. Spatial scale: extensive. Frequency: every five to ten years.

Land cover—Land cover maps could be generated on a decadal basis. The land cover maps will be used to calculate changes in areas of the various land cover classes. The classification and mapping will be done once every 10 years. Most of the classification can be done using the network of ground-based vegetation monitoring plots, but additional semiquantitative vegetation plots will need to be established to cover the range of vegetation and spectral characteristics.

ATV Trail Network Mapping—ATV trail network monitoring via a combination of remote sensing (aerial imagery, IKONOS imagery) and limited GPS fieldwork using aircraft; vegetation condition monitoring of ATV impacts where appropriate.

Current Monitoring: Landcover mapping: ABR five-year project.

Key References:

Hope, A., W. Boyton, D. Stow, and D. Douglas. 2003. NOAA-AVHRR Estimates of Vegetation Production for Three Arctic Tundra Ecosystems. International Journal of Remote Sensing **24**:3413–3425.

Hope, A. S., J. S. Kimball, and D. A. Stow. 1993. The Relationship Between Tussock Tundra Spectral Reflectance Properties and Biomass and Vegetation Composition. International Journal of Remote Sensing **14**(10):1861–1874.

Hope, A. S., K. R. Pence, and D. A. Stow. 2005. NDVI From Low Altitude Aircraft and Composited NOAA AVHRR Data for Scaling Arctic Ecosystem Fluxes. International Journal of Remote Sensing **26**:1771–1776.

Jorgenson, M. T., J. E. Roth, M. Emers, W. Davis, S. F. Schlentner, and M. J. Macander. 2004. Landcover Mapping for Bering Land Bridge National Preserve and Cape Krusenstern National Monument, Northwestern Alaska. Final report prepared for National Park Service, Anchorage, Alaska, by ABR, Inc., Fairbanks, Alaska.

Stow, D. A., A. Hope, D. Mcguire, D. Verbyla, J. Gamon, and 19 others. 2004. Remote Sensing of Vegetation and Land-Cover Change in Arctic Tundra Ecosystems. Remote Sensing of Environment **89**:281–308.

Sturm, M., C. Racine, and K. Tape. 2001. Increasing Shrub Abundance in the Arctic. Nature **411**:546.

Linked Vital Signs: Climate and Weather, Terrestrial Vegetation and Soils, Snow and Ice, Surface Water Dynamics and Distribution, Permafrost and Thermokarsting, Invasive/Exotic Species, Fire Extent and Severity

Vital Sign: Human Effects: Point Source Pollution

Description: Because ARCN is roadless and sparsely inhabited, human effects in ARCN and surrounding areas are largely traceable to point sources. Nonpoint source effects such as air contaminants are covered in other vital signs. Human-caused pollution has the potential to dramatically affect ecosystem integrity. The time scale of the effect may be immediate, as in the case of an oil spill washing ashore, or gradual, as in the case of dust palliative leaching into stream systems.

At this time, some point sources of pollution can be identified: industrial sources, community development impacts; and regional infrastructure impacts. One of the major industrial sources of pollution is the TeckCominco Red Dog Mine. Impacts of the mine to surrounding park ecosystems include ore spills, haul road dust, dust palliatives, fuel spills, power plant and combustion engine emissions, and heavy metal accumulation.

Current community development impacts include road construction for gravel sources, noise from aircraft, and trash and sewage disposal into headwater rivers. The main regional infrastructure impact of concern is beach erosion due to the increased use of beach stabilization methods (e.g., Shishmaref) and ATV traffic.

Significance: This vital sign is one of the rare circumstances where impacts may be attributed directly to human action and liability may be assessed in terms of corrective action, mitigation, or damages. Vegetation composition and distribution; primary productivity; groundwater and surface water quality; faunal composition, distribution, and behavior; noise level; and visibility all may be affected by point-source, human-caused pollution. Point-source effects may be attributed and/or legally assessed.

Monitoring Questions:

- What is the near-shore water quality adjacent to the Red Dog Mine port site? How is the water quality changing over time?
- What is the water quality in streams and lakes near Red Dog Mine, the port site, and the haul road? How is water quality changing over time?
- What is the water quality currently downstream from villages?
- What is water quality in lakes used for float plane landings (need to establish baseline in case of fuel spills)?
- What are the levels of contaminants in flora and fauna along the Red Dog haul road? Are levels changing over time?

Proposed Metrics: Water quality, contaminant loads in flora and fauna in terrestrial and aquatic ecosystems, beach debris, collection of baseline data in currently unimpacted areas for future reference

Specific Methods, Spatial Scale, and Frequency of Measurement: Track economic development meetings, planning, and activities within and around the ARCN parks; water quality measurements for heavy metals in streams and lakes in Cape Krusenstern and downstream from villages; tissue samples from flora and fauna in terrestrial and aquatic ecosystems where point-source pollutants are expected to occur; water quality in lagoons of CAKR and BELA; measure coastal water quality; water quality in “landable lakes”

Linked Vital Signs: Air Contaminants, Wet and Dry Deposition of Various Pollutants, Water Quality, Coastal Lagoon and Estuaries, Terrestrial Vegetation and Soils, and Various Mammal Vital Signs

Vital Sign: Rare and Unique Species/Communities/Habitats/Ecosystems

Description: Many unique species (e.g., muskox), communities (arctic tundra vegetation, lichen-dominated barrens) and features (maar lakes such as Devil Mountain Lake, sand dunes, lava beds, arctic springs) exist in ARCN parks.

Significance: NPS has a mandate to protect rare species, communities, habitats, and features within its broader mandate to preserve the park's flora and fauna. Many of ARCN's rare entities are relict species, communities, or habitats from a Beringian past. The study of these communities is critical to understanding their status, and their roles within their unique habitats in addition to the broader ecosystem.

Monitoring Questions:

- What rare and/or unique species/communities/habitats/ecosystems are present in ARCN parks?
- Are rare species/communities/habitats/ ecosystems being adversely effected by anthropogenic stressors?

Proposed Metrics: Rare plant surveys, rare animal population census, rare community study focusing on status and trends in physical habitat and community structure.

Specific Methods, Spatial Scale, and Frequency of Measurement: Population size could be estimated for rare plant species and rare animal taxa. Targeted of specific communities or ecosystem types could be done (maar lakes, sand dunes, lava beds).

Current Monitoring: Muskox population census by ADFG.

Key References:

Alaska Department of Fish and Game. 2005. Muskox management report of survey and inventory activities 1 July 2002 to 30 June 2004. Edited by C. Brown. Juneau, Alaska: Alaska Department of Fish and Game.

Hunt, D. 1997. *Aster yukonensis* on the Great Kobuk Sand Dunes. Western Arctic National Parklands, Nome, Alaska. Unpublished report.

Mann, D., Heiser, P. A., and B. P. Finney. 2002. Holocene history of the Great Kobuk Sand Dunes, Northwestern Alaska. Quaternary Science Reviews 21(4):709-731.

Parker, C. L. In prep. Vascular Plant Inventory of Alaska National Parklands: Bering Land Bridge National Park, Cape Krusenstern National Monument, Gates of the Arctic National Park and Preserve, Kobuk Valley National Park, and Noatak National Park.

Holt, E.A., B. McCune, and P. Neitlich. 2006. Gradient Analysis of Macrolichen Communities in the Bering Land Bridge National Preserve, Alaska, USA. Journal of Vegetation Science in review.

Linked Vital Signs: Terrestrial Vegetation and Soils, Stream Communities and Ecosystems, Lake Communities and Ecosystems, and Muskox

Vital Sign: Stream Communities and Ecosystems

Description: ARCN is home to thousands of miles of unique and fragile stream ecosystems. The primary threats to stream ecosystems in ARCN are accelerated warming, changes in precipitation patterns due to climate change, the global transport and accumulation of pollutants, the Red Dog Mine (the world's largest lead and zinc mine), and the potential overharvest of key species by humans. This vital sign refers to the suite of physical, chemical, and biological attributes of rivers and streams that are susceptible to such threats and that could be used to determine the health of aquatic ecosystems.

Significance: Conditions in the surrounding watershed often directly impact streams and rivers. Changes in stream characteristics, such as water chemistry, stream flow and biological diversity will often reflect changes in the surrounding landscape. For example, drastic changes in the landscape such as those caused by melting permafrost (thermokarsting) could have widespread implications for stream ecosystems.

Monitoring Questions:

- How is diversity and species composition in ARCN streams changing in response to human-induced environmental change?
- Are there significant shifts in biodiversity or ecosystem processes in streams due to global warming?
- How are physical and chemical attributes of streams changing due to accelerated climate change?
- How are aquatic ecosystems being affected by changes in precipitation?
- What changes in water chemistry are occurring? How are changes in water chemistry influencing primary productivity?
- How will the distribution of marine-derived nutrients change over time? Will there be a decrease in marine-derived nutrients (MDN) moving upstream? How will instream foodwebs upstream be affected by MDN?
- Are contaminants present in stream ecosystem compartments (biotic and abiotic)? What are the sources and pathways of contaminants?

Proposed Metric: The basic suite of physical, biological, and chemical parameters for sampling wadeable streams in ARCN are: (1) discharge; (2) substrate bank and riparian characterization; (3) nutrients (especially C, N, and P) and trace elements; (4) pH; (5) dissolved oxygen; (6) specific conductance; (7) water temperature; (8) metals (using ICP or mass spectrometer); (9) total suspended particles; (10) chlorophyll *a* and algae; (11) bryophytes; (12) macrophytes if present; (13) benthic invertebrates (biomass, functional group, and diversity); and (14) fish if present.

Specific Methods and Frequency of Measurement: Due to the prohibitive logistics costs of getting to any area in ARCN, wadeable streams should be sampled more intensively than the Water Resource Division's minimum requirements for parks in the lower 48 states. To save time, macroinvertebrates could be sampled using EPA's Rapid Bioassessment protocols or multivariate metrics such as RIVPACS. Spatial scale could be extensively throughout the park and intensively at a subset of streams less frequently (say at five-year intervals).

Current Monitoring: Preliminary biodiversity and landscape classification of aquatic ecosystems in the Noatak watershed (2005–2008).

Key References:

Hauer, F. R., and G. A. Lamberti, editors. 1996. Methods in Stream Ecology. Academic Press, San Diego, CA.

Huryn, A. D., K. A. Slavik, R. L. Lowe, S. M. Parker, D. S. Anderson, and B. J. Peterson. 2005. Landscape Heterogeneity and the Biodiversity of Arctic Stream Communities: A Habitat Template Analysis. Canadian Journal of Fish and Aquatic Sciences **62**: 1905–1919.

Oswood, M. W., J. G. Irons III, and A. M. Milner. 1995. River and Stream Ecosystems of Alaska. Pages 9–32 *in* C. E. Cushing, K. W. Cummins, and G. W. Minshall, editors. Ecosystems of the World 22: River and Stream Ecosystems.

Linked Vital Signs: Climate and Weather, Snow and Ice, Wet and Dry Deposition of Pollutants, Air Contaminants, Invasive and Exotic Species and Diseases, Point Source Human Effects, Subsistence/Harvest, Bird Assemblages, Surface Water Dynamics and Distribution, Lake Communities and Ecosystems, Lagoon Communities and Ecosystems, Terrestrial Vegetation and Soils, Permafrost and Thermokarsting, Fire Extent and Severity, and Brown Bears.

Vital Sign: Subsistence/Harvest

Description: While most national parklands do not allow the consumptive use of their resources, ARCN does. The enabling legislation for ARCN parklands provides for the traditional subsistence use of resources by 21 neighboring communities. This vital sign would focus some of our effort on monitoring harvests of wild, renewable resources by subsistence users.

Significance: These uses pose significant potential impacts to the renewable resources (especially the fish and wildlife) of the ARCN parklands. A sample of three of these communities—Deering (population 148), Noatak (population 379), and Shishmaref (population 560)—will begin to provide an understanding of the magnitude of pressure on those resources. Together, in one year, these three communities harvested 718,000 pounds of edible resources for a per capita harvest of 661 pounds per person. A partial translation of this harvest into numbers of animals or units of harvest includes the following: 1,099 caribou, 85 moose, 11 brown bears, 27 wolves, 31 wolverines, 22,980 salmon, 6,697 migratory birds, 1,461 gallons of berries, and 858 gallons of greens. The ARCN parklands are also open to trapping and sport hunting. Increasing population within the region, increasing sport hunting pressures in the preserves, and environmental impacts to resource populations combine to raise concerns about long-term health of the resources and the necessity to monitor both the pressures and the status of the resources.

Monitoring Questions:

- How do harvest patterns change over time in terms of spatial distribution, magnitude, composition, and seasonality?
- How are populations of harvested species changing according to past and current harvest practices?
- What are the impacts of consumptive use on stream, lake, and lagoon ecosystems?

Proposed Metrics: Most harvest data is collected in community surveys as the number of individuals of a given species or resource category per household harvested in a year. A few resources such as greens or berries may be treated more generically and expressed in terms of some common measurement such as pounds or buckets. These figures are then expanded (depending on the sample) to the community level and may ultimately be expressed in terms of pounds of useable weight per capita of a given species or resource category.

Specific Methods, Spatial Scale, and Frequency of Measurement: Household surveys would be conducted to determine the number harvested by species or harvest category. Comprehensive baseline surveys should be done at least once per human generation (approximately every 20 to 30 years).

Current Monitoring: (1) National Park Service, ADF&G Division of Subsistence, Maniilaq Association, The Harvest of Key Fish and Wildlife Species for Selected Villages in GMU 23; and (2) National Park Service, ADF&G Division of Subsistence, A Baseline Harvest Study of Kiana, Alaska.

Key References:

Alaska Department of Fish and Game. 2001. Community Profile Database. Microcomputer database updated 2001. Alaska Department of Fish and Game, Division of Subsistence, Juneau, AK.

Magdanz, James S., Charles J. Utermohle, and Robert J. Wolfe. 2002. *The Production and Distribution of Wild Food in Wales and Deering Alaska*. Technical Paper No. 259. Alaska Department of Fish and Game, Division of Subsistence, Juneau, AK.

Linked Vital Signs: Various Mammal Vital Signs, Bird Assemblages, Fish Assemblages, Terrestrial Vegetation and Soils, Lake Communities and Ecosystems, Stream communities and Ecosystems, Lagoon Communities and Ecosystems

Vital Sign: Terrestrial Vegetation and Soils

Description: The most conspicuous and recognizable landscape-scale change in biota in the Arctic is the northward shift in treeline/shrubline. Treeline is advancing and shrubs are expanding both northward and to higher elevations in ARCN. Treeline advance and shrub expansion is complex and dependant on a variety of factors such as biogeochemical cycling, plant phenology and reproduction, and a variety of soil characteristics.

Significance: Treeline advance and shrub expansion and associated soil characteristics represent major changes for tundra ecosystems, influencing all ecosystem properties. These vegetation migrations are also useful indicators of climate change. Spatial and temporal shifts in terrestrial primary productivity reflect changes in dominant plant species vigor, range, and composition which are, in turn, the products of large-scale processes and events. Primary productivity can be assessed remotely (via remote sensed imagery) and so could be used in a more extensive sampling scheme. Changes in community structure are key both to ecosystem processes and to our understanding of changes in climate, air quality, herbivore/ungulate use patterns, succession, fire, and other disturbance.

Monitoring Questions:

- Are changes in land cover and vegetation composition occurring?
- Has the phenology of vegetation changed?
- What is the distribution of vegetation across the landscape and how is it changing?
- How is forest and shrub distribution changing?
- How do shifts in human-caused perturbations affect biodiversity and native species?
- Are contaminants levels in terrestrial ecosystems of ARCN changing?
- How will atmospheric contaminants affect plant community composition and distribution?
- What changes in biodiversity will alter key ecosystem processes within the parks?
- How will long-term climate change affect reservoirs of soil carbon and impact large-scale nutrient dynamics within ARCN?
- What are the impacts of melting permafrost on nutrient cycling and element transport in soils?
- How will long-term climate change affect reservoirs of soil carbon and impact large-scale nutrient dynamics within ARCN?

Proposed Metrics: Plant community structure (species cover, diversity, biomass, community structure relative to environmental gradients); terrestrial primary production, NDVI, growth rate measures (tree/shrub rings); phenology; vegetation responses to anthropogenic stressors (e.g., climate change, contaminants, exotic species, altered fire regime); and (5) soil carbon and nutrient analysis

Specific Methods, Spatial Scale, and Frequency of Measurement: Network-scale quantitative vegetation surveys using permanent plots with high repeatability across observers. Main measurements would be percent cover by species and vegetation group and a typical suite of easily obtained environmental covariates including slope, aspect, elevation, landscape position, topography, depth of active layer, soil structure, percent rock, moisture status, biomass clipping in intensive sites, NDVI, and tree coring at boreal forest vegetation plots.

Current Monitoring: LTER sites at Toolik and Bonanza Creek—both outside of ARCN but at the edges of the network's ecosystems (i.e., coastal plain tussock tundra and boreal forest). ARCN landcover mapping classification, lichen community classification, and baseline monitoring in NOAT and BELA.

Key References:

Chapin, F.S.I. III, R. L. Jefferies, J. F. Reynolds, G. R. Shaver, and J. Svoboda. 1992. Arctic Ecosystems in a Changing Climate: an Ecophysiological Perspective. Academic Press, New York.

Walker, D.A., W. A.Gould, H. A. Maier, and M. K. Raynolds. 2002. The Circumpolar Arctic Vegetation Map: AVHRR-derived Base Maps, Environmental Controls, and Integrated Mapping Procedures. Int. J. Remote Sensing **23**:2552–2570.

Linked Vital Signs: Weather and Climate, Terrestrial Landscape Patterns and Dynamics, Air Contaminants, Wet and Dry Deposition of Various Pollutants, Bird Assemblages, and various Mammal vital signs

Vital Sign: Wet and Dry Deposition of Various Pollutants (Including Inputs to Terrestrial and Aquatic Ecosystems)

Description: Despite the pristine appearance of the arctic parklands, the steady input of contaminants from both local and global sources makes pollution a primary concern in ARCN. Inputs of pollutants (from local and global point and nonpoint sources) to ARCN ecosystems through wet and dry deposition could have profound impacts on biological and/or biogeochemical cycles in terrestrial and aquatic systems. The cumulative effects of multiple pollutants and the bioaccumulation of some pollutants (e.g., organic compounds and toxic trace metals) could have adverse effects on the health and populations of park species including subsistence species.

Significance: Pollutants such as persistent organic pollutants, toxic trace metals, sulfur, and nitrogen are known to have adverse effects on many species. The pollutants can be transported from either local or distant sources and are deposited in the sensitive ecosystems of the ARCN parks where they accumulate. Many of these pollutants are known to bioaccumulate in organisms higher in the food web.

Monitoring Questions:

- Are contaminants present and in what ecosystem compartment (biotic or abiotic)?
- What are the sources and pathways of contaminants?
- Are contaminants levels in freshwater, coastal, and terrestrial ecosystems of ARCN changing?
- How do inputs of trace metals, pollutants, and organic matter interact with biogeochemical cycles?

Proposed Metrics: Atmospheric particulate matter mass and composition; gaseous and particulate persistent organic pollutant concentration measurements; wet and dry deposition rates; radioactivity and contaminant concentrations in animal fat, fish tissue, lichen, moss, other terrestrial vegetation, macroinvertebrates, sediments, etc.

Specific Methods, Spatial Scale, and Frequency of Measurement: Sediment cores could be taken to compare current and past deposition levels. Both extensive monitoring of tissue concentrations of metals, sulphur, and nitrogen throughout the parks, and intensive tissue sampling around point sources such as the Red Dog Mine haul road and port site could be important for monitoring. Monitoring should be targeted for both deposition and for bioeffects of selected sensitive taxa. Tissue could also be taken from fish, large animals, and macroinvertebrates to monitor concentration levels and, if appropriate, to monitor biological response. For the bioaccumulation determination, samples should be collected for species at different trophic levels in the parks' ecosystems (see AMAP 1998, Protocols).

Current Monitoring: NEWNET sites in Kotzebue, Nome and Point Hope for radiological species

Key References:

Arctic Monitoring and Assessment Program. 1998. AMAP Assessment Report: Arctic Pollution Issues. Arctic Monitoring and Assessment Programme (AMAP), Olso, Norway.

Polissar, A., P. Hopke, W. Malm, and J. Sisler. 1998. Atmospheric Aerosol Over Alaska 1. Spatial and Seasonal Variability. Journal of Geophysical Research **103**(D15):doi: 10.1029/98JD01365.

Linked Vital Signs: Climate and Weather, Air Contaminants, Terrestrial Vegetation and Soils, Bird Assemblages, Fish Assemblages, Various Mammal Vital Signs, Stream Communities and Ecosystems, Lake Communities and Ecosystems, Lagoon Communities and Ecosystems

Vital Sign: Water Quality

(Note: Integrated approach, so within Streams, Lake and Lagoons vital signs)

Description: ARCN contains a complex mosaic of aquatic ecosystems that is a direct result of the diverse array of geologic processes that have shaped this landscape. High gradient streams, large meandering rivers, crystal clear streams, coastal lagoons, maar lakes, deep glacial lakes, and small shallow ponds are just some of the aquatic features that persist in this ancient landscape. These parks experience an interesting dichotomy of human activity. The primary threats to the freshwater ecosystems of ARCN are global climate change, the global transport and accumulation of pollutants, the Red Dog Mine (the world's largest lead and zinc mine), and human use. This vital sign refers to the suite of physical, chemical, and biological attributes of rivers, streams, lakes, wetlands, and lagoons that are susceptible to such threats and that could be used to determine the health of aquatic ecosystems.

Significance: Maintaining healthy aquatic ecosystems is essential to the mission of ARCN for a variety of reasons. These parks contain a large number of the nation's wild and scenic rivers as well as some of the nation's most pristine aquatic ecosystems. Documenting environmental impacts from industrialized and/or heavily used areas of the parks will help the parks manage these unique resources. Water quality also influences nutrient cycling, species composition, and other important ecological functions that occur in rivers, streams, lakes, coastal lagoons, and wetlands.

Monitoring Questions:

- What is the water quality in streams, lakes, coastal lagoons, and wetlands in ARCN and how is it changing over time?
- How is water quality in streams, lakes, coastal lagoons, and wetlands being affected by changes in temperature and precipitation?
- How is water quality of rivers, streams, lakes, coastal lagoons, and wetlands changing in response to changes in land cover and vegetation composition?

Proposed Metrics: The basic suite of water-quality parameters for sampling in ARCN should be: major and minor trace elements, pH, turbidity, chlorophyll, water color, secchi depth, sediment, metals, dissolved oxygen, specific conductance, water temperature, discharge, metals (using ICP or mass-spectrometer: entire suite and especially copper, chromium, lead, zinc, nickel, mercury), total suspended solids, base cations (especially CA, Mg, K, and Na).

Specific Methods, Spatial Scale, and Frequency of Measurement: Measurements of water quality parameters in streams, lakes, coastal lagoons, and wetlands.

Current Monitoring: ARCN has undertaken a freshwater initiative for the Noatak National Preserve in order to collect basic physical, chemical, and biological data in lakes and streams of the NOAT.

Linked Vital Signs: Stream Communities and Ecosystems, Lake Communities and Ecosystems, Lagoon Communities and Ecosystems, Weather and Climate, Snow and Ice, Rare Communities/Habitats/Ecosystems, Air Contaminants, Wet and Dry Deposition of Various Pollutants, Terrestrial Vegetation and Soils

Vital Sign: Sea Ice

Description: The ecological dynamics and taxonomic diversity of the coastal environment of ARCN are governed largely by the extent and duration of sea ice. Sea ice is important because it buffers the water from extreme atmospheric temperatures; it has a high albedo affecting the amount of sunlight absorbed in the arctic, and it forms an important biological habitat for seals, polar bear, arctic fox, and other animals that hunt and feed on the ice. Sea ice also forms an important barrier to international shipping lanes, reducing the exposure of ARCN coastlines to ocean-going threats much of the year. Sea ice has been shown to be undergoing dramatic changes in the thickness and extent that may profoundly impact ARCN coastlines. Furthermore, sea ice is thought to be a sensitive indicator of climate change in high-latitude areas.

Significance: Sea ice is an important hydrologic variable which increases in significance with latitude and elevation, and produces a diverse array of impacts on physical, chemical, and ecological processes. Formation and movement of coastal sea ice may affect prey and predators directly, by bulldozing intertidal habitats and controlling access to open water or preferred habitats, or indirectly, as changes in the sea ice cover affect landscape variables such as coastal erosion.

Monitoring Questions:

- What is the annual and seasonal variability in timing and extent of shorefast sea ice?
- Is the duration and thickness of sea ice changing?
- What is the variability in annual snowcover on shorefast sea ice?

Proposed Metrics: Aerial extent and duration of ice cover, ice thickness, snow cover on sea ice

Specific Methods, Spatial Scale, and Frequency of Measurement: Many organizations are currently monitoring the extent, duration and thickness of sea ice using a variety of techniques, including multispectral satellite imagery, ice-profiling sonar and submarine-based sonar, and web cams. The most feasible approach for monitoring sea ice along the ARCN coastline is to acquire data from these institutions annually and populate a network database on sea ice. The NOAA Sea Ice Center, Cold Regions Research and Engineering Laboratory, the University of Alaska Geophysical Institute and International Arctic Research Center are potential data sources.

Current Monitoring: NOAA Sea Ice Center http://www.arctic.noaa.gov/index.shtml, Cold Regions Research and Engineering Laboratory http://www.crrel.usace.army.mil/sid/IMB/, International Arctic Research Center, and the UAF Geophysical Institute

Linked Vital Signs: Climate and Weather, Coastal Erosion/Sedimentation/Deposition, Lagoon Communities and Ecosystems, Snow and Ice, and Subsistence/Harvest

Vital Sign: Snow and Ice (not including sea ice)

Description: Snow and ice are dominating ecosystem influences in ARCN. Snow and Ice affect landscape vegetation patterns, drainage patterns, nutrient cycling, water quality, productivity of plants and animals, the degree and types of disturbance events, the timing of migratory and breeding events of organisms, predator-prey relationships, and the distribution of plants and animals. Ice formation, thickness, and breakup are also key indicators of regional climate, especially in the data-sparse regions that characterize much of the network.

Significance: Snow and ice exert strong influences in ARCN due to the length of time they are present on the landscape relative to low-latitude regions and the thermal properties of snow and ice. Variation in the extent and duration of snow and ice will substantially affect the nutrient cycling, hydrology, types and extent of disturbance events, and the distribution and productivity of flora and fauna in ARCN.

Monitoring Questions:

- What are the annual parameters of ice and snow cover in lakes and lagoons?
- What is the depth, phenology, and distribution of snow pack in ARCN?
- What climatic factors control (precipitation, wind, weather patterns, etc.) the depth, phenology, and distribution of snow in ARCN?
- Is the duration and thickness of ice on lakes and streams changing?
- Where does aufice typically occur in ARCN?
- Are patterns of snow deposition, timing, and extent changing?

Proposed Metrics: Extent, duration, and timing of snow and ice cover; snow depth; snow volume and hardness

Specific Methods, Spatial Scale, and Frequency of Measurement: Remote sensing, daily MODIS, USDA-NRCS SNOw TELemetry sites (SNOTEL), aerial snow markers, seasonal snowpack monitoring snow courses, penetrometer

Current Monitoring: Kanuti currently has an aerial snow marker course. There are SNOTEL sites at four locations on the eastern boundary of ARCN (Imnaviat Creek, Atigun Pass, Coldfoot, and Gobblers Knob) and one site between Noatak National Preserve and Cape Krusenstern National Monument (Ikalukrok Creek).

Key References:

Liston, G. E., and M. Sturm. 1998. A Snow-Transport Model for Complex Terrain. Journal of Glaciology 44(148):498–516.

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Wilson, W. J., E. H. Buck, G. F. Player, and L. D. Dreyer. 1977. Winter Water Availability and Use Conflicts as Related to Fish and Wildlife in Arctic Alaska—A Synthesis of Information. USFW/OBS-77/06.

Linked Vital Signs: Climate and Weather, Sea Ice, Terrestrial Landscape Patterns and Dynamics, Terrestrial Vegetation and Soils, Surface Water Dynamics and Distribution, Lagoon Communities and Ecosystems, Lake Communities and Ecosystems